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Environmental Evidence

SYSTEMATIC MAP

What evidence exists for the effectiveness of on-farm conservation land management strategies for preserving ecosystem services in developing countries? A systematic map

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Abstract

Background: An extensive body of evidence in the field of agro-ecology claims to show the positive effects that maintenance of ecosystem services can have on meeting future food demand by making farms more sustainable, productive and resilient, which then contributes to improved nutrition and livelihoods of farmers. However, inconsistent effects have commonly been reported, while empirical evidence to support assumed improvements is largely lacking. Overall, a coherent synthesis and review of the evidence of these claims is largely absent from the literature.

Methods: Systematic searches of peer-reviewed research were conducted in bibliographic databases of Web of Science, SCOPUS, AGRICOLA, AGRIS databases and CAB abstracts, and grey literature from Google Scholar, and 32 subject-specific websites. Searches identified 21,147 articles. After screening, 746 studies were included in the final map.

Results: Of the 19 conservation land management practices considered, soil fertilisation (24 %), tillage (23 %), agroforestry (9 %), and water conservation (7 %) were most commonly studied. Ecosystem services most commonly studied were supporting (55 %) and regulating (33 %), particularly carbon sequestration/storage, nutrient cycling and soil/water regulation/supply. Key data gaps identified included the absence of long-term records (with datasets spanning >20 years), studies located in North and Central Africa, research that focuses on smallholder landscapes, and studies that span different scales (regional and landscape levels).

Conclusions: The study employs systematic mapping combined with an online interactive platform that geographically maps results, which allows users to interrogate different aspects of the evidence through a defined database field structure. While studies are not directly comparable, the database of 746 studies brings together a previously fragmented and multidisciplinary literature base, and collectively provides evidence concerning a wide range of conservation land management practices impacting key ecosystem services. The systematic map is easily updatable, and may be extended for additional coding, analysed to assess the quality of studies, or used to inform future systematic reviews.

Keywords: Agro-ecology, Conservation agriculture, Sustainable intensification, Ecosystem services, In-field assessment, Site-specific management, Land sharing, Evidence-based environmental policy

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Background

Over the last 80 years, the industrial agricultural revolution has made significant advances in food production. For example, in developing regions as a whole, the share of undernourished people in the total population decreased from 24 % in 1990–92 to 13 % by 2012 [1]. However, this transition also created a technology-reliant global food system and associated long-term vulnerabilities, such as dependence on crop monocultures, chemical fertilisers, pesticides, petroleum and antibiotic feed supplements [2]. The agricultural system also causes a complex interaction of environmental deterioration [2] by accounting for: 70 % of water extraction worldwide [2], consumption of one-third of all available energy [3], 75 % of all deforestation [3], 19–29 % of global greenhouse gas (GHG) emissions [4], the largest contribution of non-CO_2 GHG emissions [5], and the leading cause of biodiversity loss [2]. Moreover, these trends are increasing as agriculture intensifies and expands. For example, between 1961 and 2005 agricultural production doubled in Sub-Saharan Africa [5], and was one of the main drivers of degradation in 65 % of natural ecosystems globally [6]. In the years leading up to 2040, an estimated increase of 50–70 % in food production and availability is needed to keep pace with the demands of a global population expected to reach 8–10 billion and a concurrent decline in available arable land [6, 7]. As the population grows, per capita supply of farmland is increasingly in competition with accelerated urbanisation [8]. Income growth has also led to expansion of the global demand for meat, which has tripled in the last 50 years [9] so that livestock now consume 40 % of the global feedstock. The threat of climate disruption poses further biophysical barriers to enhancing yields, particularly in rain-fed regions. It is therefore increasingly evident that industrial agriculture is not sustainable at its current level of expansion [2, 3, 6, 10]. This view has been supported by a recent study by Ehrlich and Ehrlich [2], who describe these interconnected challenges as having the potential to lead to a global collapse in the food system, comprising of production, processing, packaging, storage, distribution, retail, consumption and disposal. Other international bodies, including the Global Alliance for Climate Smart Agriculture, the UK Government Foresight Committee [3], and the Oxford Martin Commission [10] have argued that one of the greatest challenges for the 21st century is finding the balance between providing enough food for a growing population and maintaining healthy ecosystems, while meeting the livelihood and nutritional requirements of the most vulnerable in a changing climate.

To address the challenge of identifying how to close the 'yield gap' (i.e. raise yields in less productive systems than those typical of industrial agriculture [2, 7]), many studies are now examining the impact of ecosystem service conservation strategies on agricultural productivity [11], and associated with this, the implementation of a variety of alternative practices to conventional or intensive agriculture. The Millennium Ecosystem Assessment (MA) [6] and other more recent frameworks [12, 13] have asked the question: what agricultural practices are effective, practical, affordable, and scalable? For the purpose of this study, 'conservation land management practices' are those practices that are adopted with the aim of preserving or enhancing ecosystem services without compromising farm production, and may be adopted before, during, or after cultivation [14]. These conservation land management strategies may be active, such as surface crop residue management, or passive, such as the preservation of native vegetative patches in fields [15]. Practices may incorporate principles of multifunctional agriculture (e.g. simultaneously producing food and non-food commodities, maintaining wild crop varieties, traditional landraces and local culture [16]), sustainable intensification (i.e. relieving pressure on land expansion and limiting forest encroachment [5]), and conservation agriculture (i.e. including practices of no-tillage, permanent soil cover using crop residues or cover crops, and crop rotation [17]), amongst others. As conservation land management practices often require minimal capital investment and inputs, provide multiple benefits (e.g. food, fodder, and enhanced soil quality), and show significant effects over short periods [14], they have opportunities for enhancing smallholder production.

Despite a growing interest in this area, there still appears to be a lack of a coherent evidence base showing how effectively these management strategies preserve or enhance ecosystem services overall. This may in part be because identifying accurate quantitative measurements, interpreting interrelations, and synthesising how the output can translate into practical management techniques is exceedingly complex for four main reasons. First, changes in conservation land management may affect various ecosystem services differently, and management requires making judgments about trade-offs depending on the service, temporal horizon, spatial scale or geography [18]. Second, there is an apparent deficiency of indicators or proxies of ecosystem processes. Those that are available often have incomplete datasets or the benefits and/or disservices of particular practices are inconsistently reported. For example, some studies report that long-term no-till can improve soil fertility, recovery and decrease erosion, but conflicting reports state that no-till also leads to soil compaction, can limit water infiltration and hinders seed germination [19, 20]. Third, the issue of scale brings another level of complexity, because some benefits are often only measurable at larger scales. For example, the impacts of conservation land management practiced on a local level may only be visible over a large area or over a long period of time, whereas they may only have been measured at the farm scale, and the reported results are therefore incomplete. Fourth, much of the evidence is spread across different disciplinary 'silos', with very limited synthesis. Some studies may also overstate the benefits of land management strategies.

When evidence is so extensive and disparate, a first step in an informational synthesis is a systematic map: a rigorous methodological tool for data extraction of peer-reviewed and grey literature [21–23]. Systematic maps can be used to describe the nature, volume and characteristics of research in a broad topic area, and may be used to identify trends in the literature and knowledge gaps for future analysis. Systematic maps follow the same rigorous systematic processes as systematic reviews, being transparent and repeatable to search for and collate evidence. However, critical appraisal of the quality of the evidence is often either absent or limited in depth, and results from studies are not extracted or synthesised [24, 25].

Previous attempts to synthesise the body of research that examines on-farm conservation management practices have focused on particular regions (particularly Africa [26, 27]), a limited set of practices [17], or the evaluation of management outcomes purely in terms of crop responses [26]. Our systematic map builds on this research both geographically, being the first effort to synthesise the evidence in developing countries broadly and in terms of the range of management strategies and ecosystem services studied. This study is among the first (see also [28, 29]) to present the results of a synthesis of environmental evidence using an online interactive geographic map.

The aim of this systematic map is to review the state of evidence that reports on the effectiveness of on-farm conservation land management for protecting or enhancing ecosystem services. The objectives of the systematic map are:

1. To collate studies reporting evidence on the effectiveness of on-farm conservation land management practices on ecosystem service provision in agricultural landscapes in low-income and developing countries.
2. To map regions where on-farm assessments of conservation land management in low-income and developing countries have been undertaken.
3. To make information easily accessible by producing an online interactive map, searchable by topic.

We aim to provide a detailed summary of different strategies proposed and tested, for different crops in different regions, and over different timeframes. Moreover, we identify the pathways by which practices are assumed to influence ecosystem service provision by reporting on measurable indicators assessed in studies. Developing countries are the focus of the review for three key reasons. Firstly, developing regions are where much of the world's agricultural expansion is occurring [3], yet 80 % of arable land is already used [30] and croplands yield well below their potential [31]. Secondly, in some cases, developing regions may also depend on ecosystem services rather than technological inputs to support agriculture, due to lower financial, technical and credit-borrowing capacity [1]. Thirdly, according to the FAO, of the 795 million people classified as undernourished worldwide, 780 million are in developing regions [1]. We anticipate four key end-users for the information that results from this systematic map: land owners and managers; local decision makers and programme managers; national and international policy makers; and researchers. The information highlights important research directions which can help to develop monitoring baselines, diagnose environmental problems, identify systems close to environmental thresholds, and thus evaluate the benefits and trade offs of strategies to implement at the farm level.

Methods

The systematic map followed a published a priori protocol [32]. Definitions of terms were developed collaboratively during the work (Additional file 1). These were used principally for searches and screening, to improve rigour and overcome possible ambiguity between reviewers. Full details are provided in Additional file 2 of the search terms, the number of records generated for specific searches, and the name, location, date of searches in bibliographic databases, online searches, key international peer-reviewed journals, and specialist organisations and online databases.

Search strategy

Key search terms

The systematic search was conducted 27 October 25 November 2014 to identify potentially relevant studies. For each search, the date, database name, search term, number of hits, number of references obtained, number of removed duplicates and observations were recorded. Search terms were disaggregated using truncation (in most databases '*') and differences in spelling were accounted for by using wildcards (mostly '?' or '$'). Elements of the search were differentiated as 'sets'. The Boolean operator terms AND, OR and NEAR were used. Search terms were as follows:

farm, agricultur*, agro$forestry, cultivat*, crop**
ecosystem, ecolog, environmental, provision*, regulat*, support*, cultur* function*, good*, process*, service**
"soil regulation", "water regulation", "nutrient

cycling", "pollinat", "cultural services", "education services", "spiritual services", "recreational services", ecotourism, "carbon regulation", "carbon sequestration", "pest regulation", "disease regulation", "fuel$wood", "building material", "flood regulation", "medicinal and aromatic plant*", "wild harvested goods", "non$timber forest product*"*
((no, reduced, zero conservation, minim) NEAR/1 till*), "green manure",rotat*,residue*,mulch*, "cover crop*", "organic matter", "crop divers*", intercrop*, "integrated pest management", assess*, survey*, sampl*, method*, measur*, test*,observ*, evaluat*, interview*, transect*, perception*, technique*, effect*, monitor*, toolkit*, "payment for ecosystem service", impact*, "experimental design"*

Sources of publications
An extensive targeted search of peer-reviewed and grey literature was conducted, including key bibliographic databases, key international journals, specialist organisations, and online databases.

Bibliographic databases The following bibliographic databases were searched:

1. Thomson Reuter's (formally ISI) Web of Science™ Core Collection http://apps.webofknowledge.com/
2. Elseviers' SCOPUS http://www.elsevier.com/online-tools/scopus
3. CAB Abstracts published by CAB International http://www.cabdirect.org/ (via ovidsp.tx.ovid.com)
4. AGRICOLA National Agricultural Library and Citation Database http://www.ebscohost.com/academic/agricola
5. AGRIS Agricultural Science and Technology Information Systems http://agris.fao.org/agris-search/index.do

Key individual journals Five key international e-journals were also hand-searched whose topic areas closely aligned with the research question, as determined in the protocol [32]. This included Ecological Indicators; Ecosystem Services; Integrated Environmental Assessment and Management; Agriculture, Ecosystems, and Environment and Field Crops Research.

Search engine searching and online call An internet search in Google Scholar was conducted to retrieve the first 200 searches (see Additional file 2 for search terms) and an online call for relevant literature was published on the Centre for International Forestry Research (CIFOR) website.

Grey literature for specialist searching Thirty-two specialist organisations and online libraries were searched for organisational reports, conference papers or proceedings, policy briefs, station and annual reports (Table 1). Given the limited search capability of databases, a hierarchical approach [33] to searching was used, converting the original string to key words (e.g. in-field assessment, ecosystem services) and topics (e.g. agriculture) (Additional file 2). Where the facilities were available, language limits to English were set. Where no search bar existed, websites were also hand-searched.

Estimating the comprehensiveness of the search
The search string was the last of 27 iterations tested in Web of Science. A test library of 30 references (see protocol [32]) confirmed the search strings captured relevant literature, balancing specificity and sensitivity [33].

Study inclusion and exclusion criterion
The following summarised criteria were established through two stakeholder workshops in February 2014, Cape Town, South Africa and June 2014, Oxford, UK.

Population
We examined studies on farms located in 74 low/middle income and developing countries. These countries were selected from three databases of globally-recognised organisations working to improve ecosystem services, reduce food insecurity and support economic development (i.e. [34–36]). Relevant farming systems were based on an extended list of the FAO major commodities list [37], including terrestrial food, cash, oil, and agroforestry crops. As determined through the peer-review process when developing the protocol [32], marine biomes or mangroves with maricultural or aquacultural activities were excluded (see Liquete et al. [38] for a review on marine ecosystem services), and livestock farming and pastures (including land covered with grass or other plants suitable for grazing) were excluded from this study.

Intervention
Studies where conservation land management strategies were adopted to support productive agriculture, while simultaneously preserving or enhancing ecosystem services were examined. However, studies assessing cultivar selection, behavioural ecology, purely agronomic or economic questions, and land uses differentiated only by crop type were excluded. Those analysing land use gradients and studies of non-point source pollution were also excluded, because these were deemed to be outside the scope of site-specific management strategies.

Table 1 Specialist organisations and online databases searched in the systematic map (note, although web addresses were correct at 02/07/2016, it may be necessary to use the search capability of the parent websites to find these resources in the future)

No.	Organisation	Website
1	Centre for International Forestry (CIFOR)	http://www.cifor.org/library/
2	Consultative Group for International Agricultural Research (CGIAR)	http://www.cgiar.org/resources/cgiar-library/
3	Alliance for a Green Revolution in Africa (AGRA)	http://agra.org/
4	International Rice Research Institute (IRRI)—library catalogue	http://ricelib.irri.org/
5	International Centre for Tropical Agriculture (CIAT)—library repository	http://library.ciat.cgiar.org/
6	Integrated Water Management Institute (IWMI)	http://www.iwmi.cgiar.org/
7	International Institute of Tropical Agriculture (IITA)	http://www.iita.org/
8	International Potato Centre (CIP)	http://cipotato.org/
9	Africa Rice Centre (Africa rice)	http://www.africarice.org/
10	World Resources Institute (WRI)	http://www.wri.org/
11	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)—OPEN access repository	http://oar.icrisat.org/cgi/search/advanced
12	Climate Change Agriculture and Food Security (CCAFS)	https://ccafs.cgiar.org/publications
13	World Agroforestry Centre (ICRAF)—publications	http://outputs.worldagroforestry.org/
14	International Centre for Agricultural Research in the Dry Areas (ICARDA)—publications and resources	http://www.icarda.org/publications-resources
15	Comprehensive Africa Agriculture Development Programme (CAADP)	http://www.nepad-caadp.net/
16	Institute of Environment and Agricultural Research (INRA)	http://www.inra.fr/en/liste/dossiers/76
17	Monsanto Agricultural	http://www.monsanto.com/products/pages/biotech-technical-publications.aspx
18	Syngenta Foundation	http://www.syngentafoundation.org/index.cfm
19	Department for International Development (DFID)–Research for Development (R4D)	http://r4d.dfid.gov.uk/
20	Ecosystem Services Partnership (ESP)	http://www.es-partnership.org/esp
21	EcoAgriculture Partners	http://www.ecoagriculture.org/
22	International Union for the Conservation of Nature (IUCN)	http://www.iucn.org/knowledge/publications_doc/publications/
23	United Nations Development Programme (UNDP)	http://www.undp.org/content/undp/en/home/librarypage.html
24	Overseas Development Institute (ODI)	http://www.odi.org/publications
25	International Maize and Wheat improvement (CIMMYT)—collections repository	http://repository.cimmyt.org/xmlui/discover
26	International Maize and Wheat improvement (CIMMYT)—library catalogue	http://repository.cimmyt.org/
27	The Economics of Ecosystems and Biodiversity (TEEB)	http://www.teebweb.org/
28	Convention of Biological Diversity (CBD)—case study database	https://www.cbd.int/case-studies/
29	Convention of Biological Diversity (CBD)—information centre catalogue	https://www.cbd.int/doc/library/books.aspx
30	Bioversity International-E-Library publications	http://www.bioversityinternational.org/e-library/publications/
31	Practical Action-Publishing	http://practicalaction.org/publishing
32	International Institute on Environment and Development (IIED)	http://pubs.iied.org/

Comparators

Within studies, comparators were defined as farms or fields without conservation land management strategies, conventional/intensive agriculture or natural sites.

Outcome

We examined the literature to look for evidence of measured changes in ecosystem services, including supporting services (e.g. carbon regulation, pest regulation, nutrient cycling, biodiversity), regulating services (e.g. water/soil regulation and supply, pollination services), provisioning services (e.g. fuel wood, medicinal and aromatic plants), and cultural services (e.g. education, recreational, spiritual, tourism, bequest or aesthetic value). We excluded non-timber forest products (NTFPs) extracted off the farm (from forests) but included NTFPs on farms (e.g.

from trees on farm boundaries or on domestic homesteads). Studies measuring outcomes on health or nutrition, including those measuring fungal pathogens and diseases, were excluded from our analyses.

Study design

We included studies that had provided grounded empirical assessments at the field level, using direct assessment of social or ecological variables. Lab-based and ex-situ methods were excluded, as were conceptual frameworks, methodologies, training manuals, conservation planning tools and regulatory/legislative frameworks. Studies that looked only at economic valuation were also excluded.

Language

Owing to limitations of time and resources, we only included studies published in English. Authors acknowledge that this may introduce a bias against studies conducted in developing countries where the official language or operation language of universities and research institutions is not English, particularly studies in Spanish, French and Portuguese. We suggest expanding to other languages of publication for future iterations.

Date

No time limitation to the search was applied. Single and multiple year studies were included, however long-term paleoecological studies were excluded.

Screening

References were filed in EndNoteX7™ reference manager [39] as separate libraries according to bibliographic source, pooled together and duplicates were removed. References were exported into a master database in Microsoft Excel for visual checks at each stage of screening, using categories of publication ID, title, year, abstract, country and URL. References were then imported into DataX systematic review evaluation software for abstract screening [40]. Title, abstract, and full text screening took place between 26 November 2014 and 9 February 2015. Five reviewers at the University of Oxford and CIFOR conducted screening at title and abstract stage. Three reviewers conducted full text screening, recording reasons for exclusion. At the title screening, the Randolph's free-marginal kappa on a random subset of 100 studies was 0.82 [41]. Where there was doubt of studies to be included/excluded, exclusion was conservative. Any ambiguities were discussed through online consultation, and references further verified by secondary reviewers. Fourteen articles were identified that were either meta-analyses or systematic reviews (not included in the systematic map database, but as Additional file 3).

The list of studies excluded at full text with reasons for exclusion is shown in Additional file 4. Hand-searched articles on organisational websites were excluded when studies described:

1. Cultivar selection, economic valuation, or purely yield impacts of management (e.g. studies in the Africa Rice Centre),
2. Concept notes, proposals, project reports and training, methodology manuals (e.g. TEEB, Comprehensive Africa Agriculture Development Programme (CAADP)), or media releases and workshop reports (e.g. Institute of Environment and Agricultural Research),
3. Programme information of funding agencies (e.g. Department for International Development (DFID)),
4. Institutions, governance and policies of poverty and development without including agriculture data (e.g. many studies of the Overseas Development Institute (ODI), and World Resources Institute (WRI)), or
5. Were not field based or excluded methodologies to directly assess ecosystem services or were not field-based (e.g. Agricultural research companies including Monsanto and Syngenta).

Data coding and extraction

Data extraction was conducted by eleven coders, who regularly met with a secondary reviewer to discuss and resolve inconsistencies between the 10th of February 2014 and the 20th of April 2015. Authors were contacted where studies did not include the site coordinates or study location ($n = 4$). We used Dropbox and Google-forms to share studies and extract the data. A coding tool (Additional file 5) for data extraction was developed with division into six categories, as illustrated in Fig. 1.

Data mapping

Following the completion of data extraction, results were placed in a searchable database as a relational Microsoft Access database (Additional file 6). Results were searchable by keyword, and cross-tabulated to identify where no research outputs were available. Qualitative and quantitative synthesis was conducted on trends, interpretation, and gap analysis from May to July 2015. Graphic visualisation for spatial analysis employed ArcGIS10 mapping software [42], using the World Geodetic System 1984 and decimal degree coordinates. Visualisation in the online interactive map was accomplished with a D3 open source JavaScript framework hosted on the Oxford Long-term Ecology Laboratory website.

A summary of each study is available by clicking on the study site, which opens a scrollable side table. The table presents the attributes stored for that study,

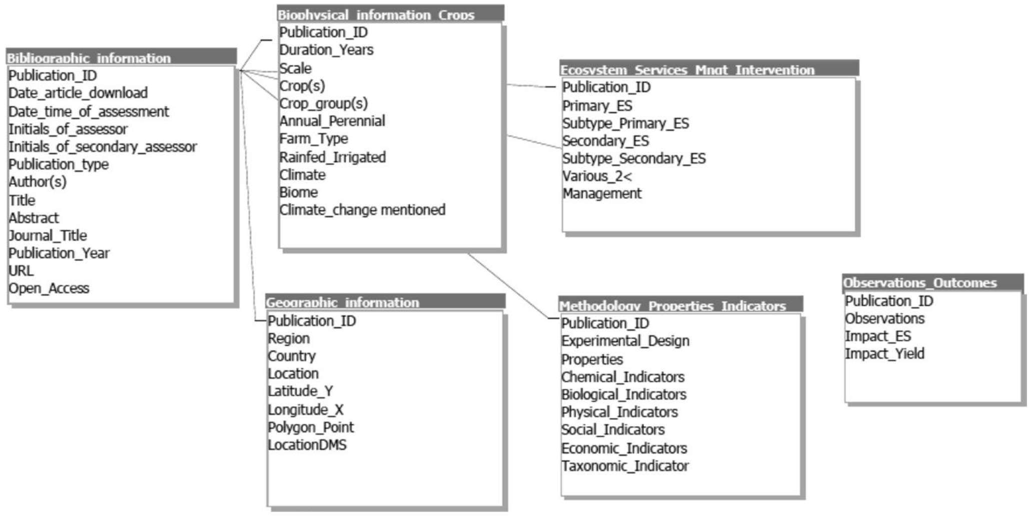


Fig. 1 Relational model of coded variables included in the systematic map as structured in the Microsoft Access (*ES* ecosystem services)

including bibliographic, biophysical, ecosystem service, and management details, plus a URL link to open access articles. A filter system allows users to choose criteria for making sites visible on the map. When a database field is selected as a filter, all the values within that field appear in a list. Selecting a set of values causes the map to present only the sites that match those values. Filters may be based on categories (e.g. smallholder farms), ranges (e.g. studies published between 1992 and 2000), or key search terms (e.g. maize crops or tillage). For example, users interested in experimental studies assessing the impact of no-till on regulating and supporting services in maize may use the map to identify 113 studies.

The online interactive map is accessible here or at https://oxlel.zoo.ox.ac.uk/resources/ecosystem-services-onfarm-conservation-map.

Results

Overall descriptive statistics

The flow chart for selecting articles for the systematic map, with results for each stage, is shown in Fig. 2 (adapted from Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA [35]). A total of 746 were included in the final systematic map. (A list extracted from the Endnote database of these articles is included in Additional file 7).

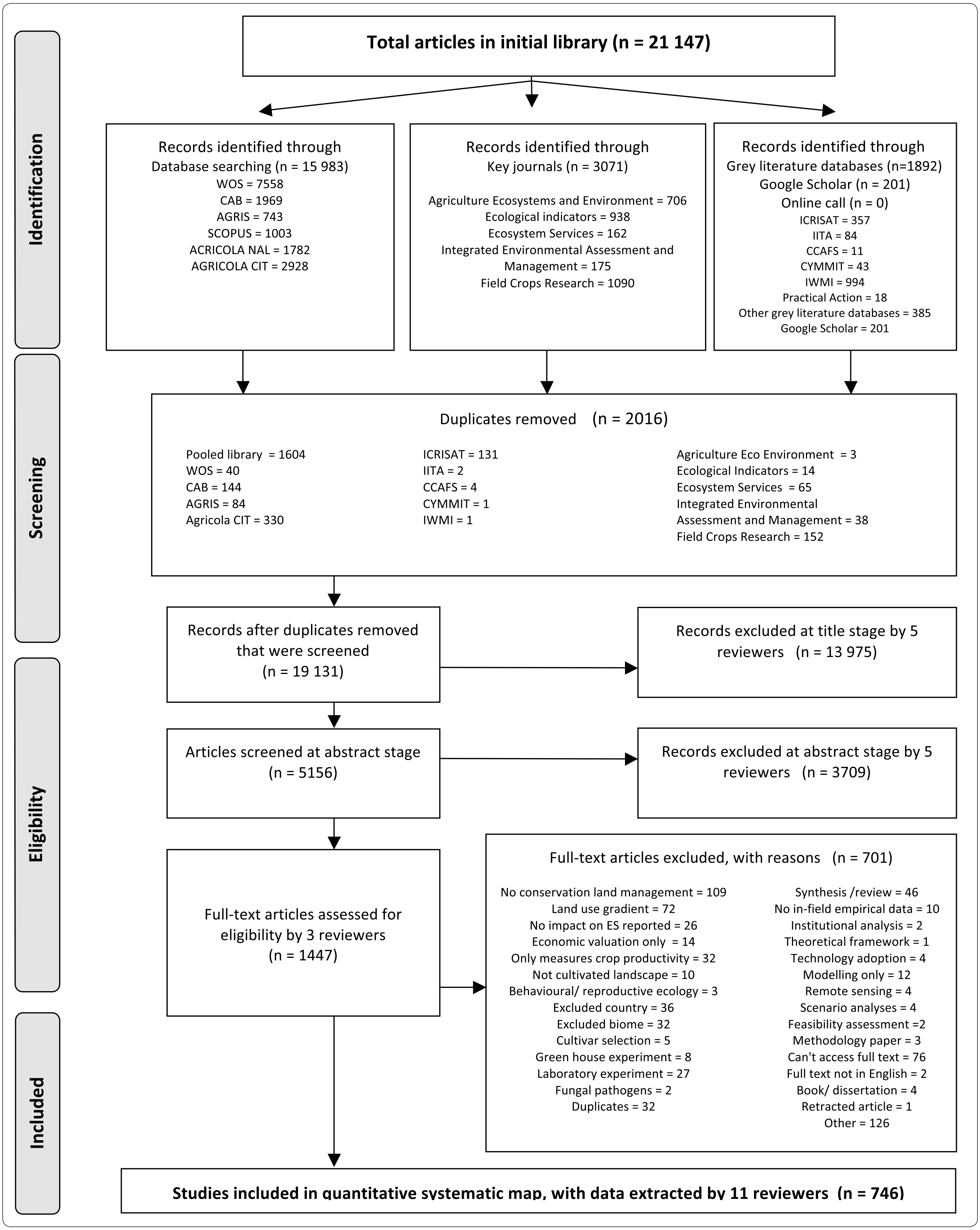
Of the 746 articles evaluating the impact of farming strategies included in the map, 576 articles were experimental in their design with treatment and control groups, 49 articles were quasi-experimental (i.e. without all factors affecting outcomes, groups controlled), and 121 were non-experimental (i.e. without any explicit manipulation of groups [24]).

Overall, the majority of articles were journal articles (97 %, $n = 727$). The remaining articles were grey literature articles (2 %, $n = 15$) composed of reports and policy documents from agricultural, developmental and environmental research agencies (e.g. Integrated Water Management Institute (IWMI)), and articles from conference proceedings (1 %, $n = 4$). Two hundred and fourteen of the 746 articles were open access of the 746 articles. This analysis differentiated between articles and studies. For example, where information from one study was presented in one or more articles but did not include the same data, studies were considered multiple outputs and included in the systematic map as such. Furthermore, 244 articles included multiple case studies, which were included in the database as separate entries for geographic mapping.

Journal titles

A total of 202 journal titles were represented. Over half of the relevant articles ($n = 434$ or 58 %) were published in

(See figure on next page.)
Fig. 2 Overview of article screening and inclusion in the systematic map. A full list of grey literature websites is listed in Table 1 and Additional file 2. (*WOS* Web of Science, *CAB* CAB Abstracts: *AGRICOLA NAL* U.S. Department of Agriculture's National Agricultural Library, *AGRICOLA CIT* U.S. Department of Agriculture's Citation Database, *ICRISAT* International Crops Research Institute for the Semi-Arid Tropics, *IITA* International Institute of Tropical Agriculture, *CCAFS* Climate Change Agriculture and Food Security, *CYMMIT* International Maize and Wheat Improvement Centre—including Library Catalogue and Collections repository, *IWMI* International Water Management Institute, *ES* ecosystem services)


Identification
Screening
Eligibility
Included
Total articles in initial library (n = 21 147)
Records identified through
Database searching (n = 15 983)
WOS = 7558
CAB = 1969
AGRIS = 743
SCOPUS = 1003
ACRICOLA NAL = 1782
AGRICOLA CIT = 2928
Records identified through
Key journals (n = 3071)
Agriculture Ecosystems and Environment = 706
Ecological indicators = 938
Ecosystem Services = 162
Integrated Environmental Assessment and Management = 175
Field Crops Research = 1090
Records identified through
Grey literature databases (n=1892)
Google Scholar (n = 201)
Online call (n = 0)
ICRISAT = 357
IITA = 84
CCAFS = 11
CYMMIT = 43
IWMI = 994
Practical Action = 18
Other grey literature databases = 385
Google Scholar = 201
Duplicates removed (n = 2016)
Pooled library = 1604
WOS = 40
CAB = 144
AGRIS = 84
Agricola CIT = 330
ICRISAT = 131
IITA = 2
CCAFS = 4
CYMMIT = 1
IWMI = 1
Agriculture Eco Environment = 3
Ecological Indicators = 14
Ecosystem Services = 65
Integrated Environmental Assessment and Management = 38
Field Crops Research = 152
Records after duplicates removed that were screened (n = 19 131)
Records excluded at title stage by 5 reviewers (n = 13 975)
Articles screened at abstract stage (n = 5156)
Records excluded at abstract stage by 5 reviewers (n = 3709)
Full-text articles assessed for eligibility by 3 reviewers (n = 1447)
Full-text articles excluded, with reasons (n = 701)
No conservation land management = 109
Land use gradient = 72
No impact on ES reported = 26
Economic valuation only = 14
Only measures crop productivity = 32
Not cultivated landscape = 10
Behavioural/ reproductive ecology = 3
Excluded country = 36
Excluded biome = 32
Cultivar selection = 5
Green house experiment = 8
Laboratory experiment = 27
Fungal pathogens = 2
Duplicates = 32
Synthesis /review = 46
No in-field empirical data = 10
Institutional analysis = 2
Theoretical framework = 1
Technology adoption = 4
Modelling only = 12
Remote sensing = 4
Scenario analyses = 4
Feasibility assessment =2
Methodology paper = 3
Can't access full text = 76
Full text not in English = 2
Book/ dissertation = 4
Retracted article = 1
Other = 126
Studies included in quantitative systematic map, with data extracted by 11 reviewers (n = 746)

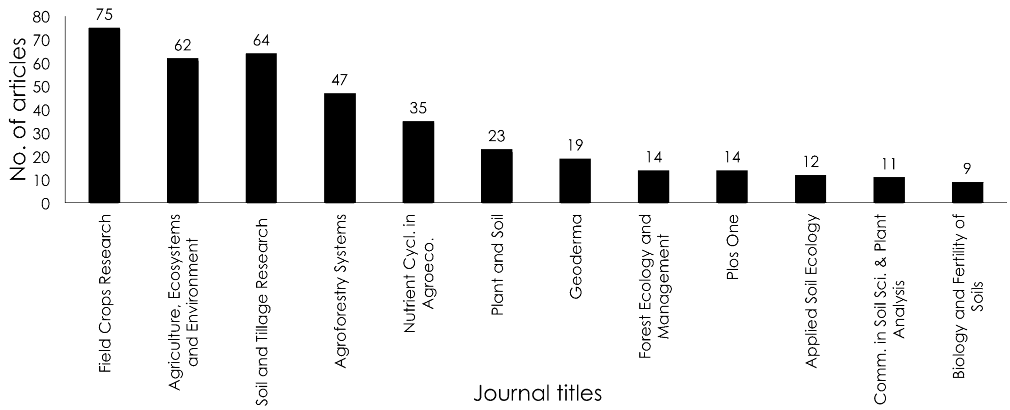


Fig. 3 Number of articles published per journal title

the 12 journals (Fig. 3). Field Crops Research, Agriculture Ecosystems and Environment, Soil Tillage Research and Agroforestry Systems and Nutrient Cycling in Agroecosystems were most frequently represented in descending order. The remaining 312 articles were published in 190 other journals.

Publication year

The earliest study recorded was published in 1984. There was an exponential increase in the number of studies published per year starting from 1992 up to 2014 when the search was conducted, with the highest number of articles published in 2013 (Fig. 4). Notable increases occurred between 2006 and 2007 and after 2011. The average rate of publication was 0.9 articles/year between 1984 and 2003: only 5 articles published before 1992, whereas 7.6 articles were published per year during the period from 1994 to 2004, and 55.4 articles/year from 2005 to 2014. Seventy-four per cent of articles were published in the last decade (2004 to present).

Recognising that scientific publications generally have been increasing in number exponentially for the last few decades, we compared the cumulative number of articles in the systematic map to a broader search in Scopus database, following Petrokofsky [25]. Scopus was searched on 10 June 2015, with the search phrase 'conservation agriculture' limited to subject areas of Life Sciences, Physical Sciences, and Social Sciences and Humanities and Environmental Science, Agricultural and Biological Life Sciences and Social Sciences. We found a proportionally greater increase in the number of studies in the systematic map ($n = 746$) compared with other generalist searches ($n = 10{,}961$) over the same time period since 1962 (Fig. 5).

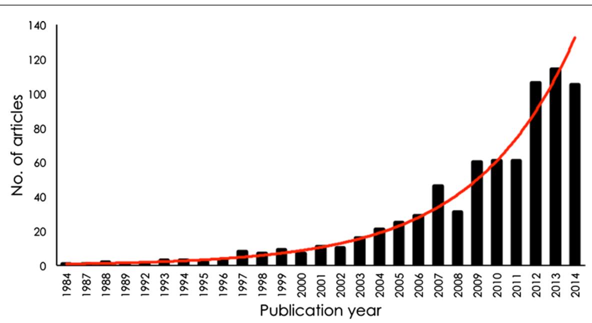


Fig. 4 Number of published studies by year showing an exponential increase (*trend line*) since 2000

Duration of study

The largest proportion of studies lasted 1 to 4 years (33 %, $n = 249$). Of the remaining studies, 21 % ($n = 156$) were less than a year in duration, 13 % ($n = 99$) 5 to 10 years, 5 % ($n = 35$) 10 - 14 years, and 6 % ($n = 44$) 15 to 19 years. Ten per cent ($n = 78$) of studies were conducted over 20 to 49 years, while only 3 studies (0.4 %) were conducted on plots over 50 or more years. Eighty-two studies did not state their duration (11 %).

Region and country of origin

Studies were spread widely across 46 countries (20 in Africa, 13 in Asia, 12 in Latin America, and 1 in Oceania). Half were located in Asia (50 %, $n = 376$), a quarter in Africa (26 %, $n = 199$) and a quarter in the Americas (24 %, $n = 182$). Countries with the most studies were China (24 %, $n = 180$), India (17 %, $n = 134$), Brazil (14 %, $n = 105$) and Mexico (7 %, $n = 54$) (Fig. 6).

In Asia, most of the studies were from Far East Asia (49 %) and South Asia (42 %). In Africa, the proportion of studies was more evenly split between East Africa, West Africa and Southern Africa (34, 28, 27 %). In West Africa, most studies were located in the English

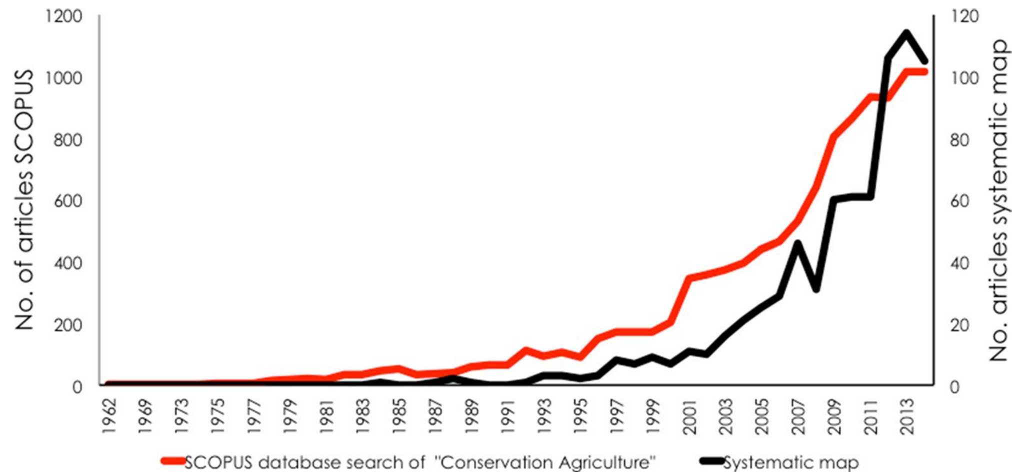


Fig. 5 Comparison of number of studies published up until 2014, comparing searches with the term 'conservation agriculture' in Scopus and results of the systematic map

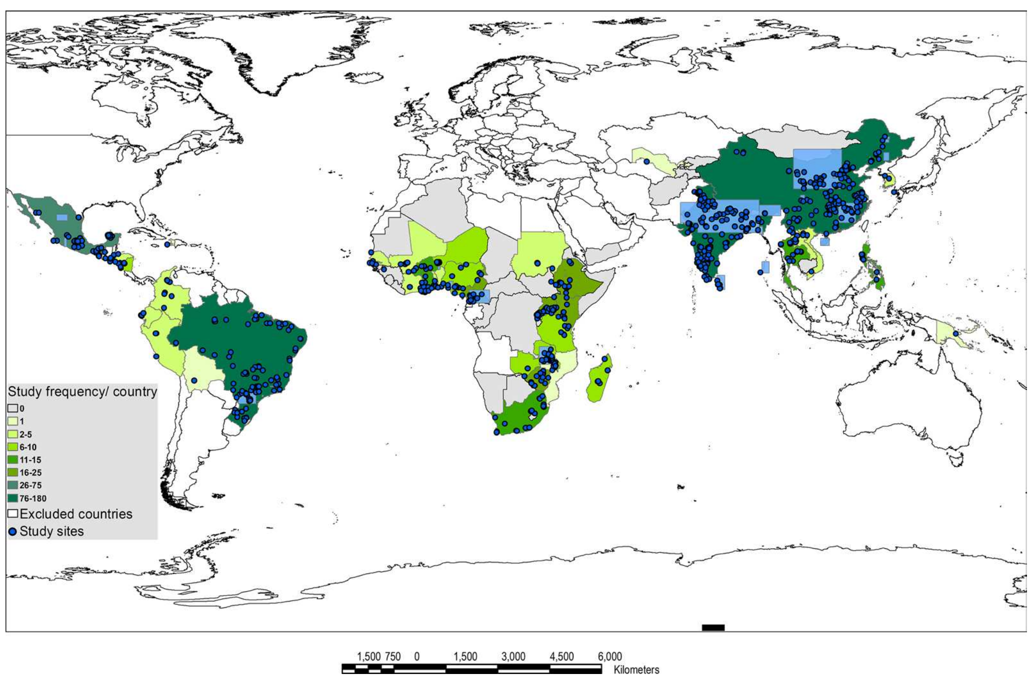


Fig. 6 Map of study site distribution and frequency included in the systematic map. Points and polygons indicate geographic locations, and the shading of countries from *grey* to *dark green* indicates the number of studies conducted in each country. The map illustrates that most studies have been conducted in China, Mexico, India and Brazil (*dark green*) ($n = 1365$), while there is a dearth of studies that have been conducted in Central, Southern and North Africa

speaking country of Ghana *(*$n = 13$) rather than the surrounding Francophone countries. Only one study was located in North Africa, while 18 were in Central Africa. In the Americas, 65 % of studies ($n = 118$) were located in South America (mostly in Brazil, $n = 105$, followed by Colombia and Peru). 64 were in North/Central America (mostly in Mexico, $n = 54$), followed by Nicaragua, Honduras and Haiti. We acknowledge these results may be an artefact of the language selection criteria.

While 74 countries were admissible in the selection criteria for the systematic map, no studies were found in 28 countries: Afghanistan; Algeria; Bhutan; Botswana; Burundi; Cambodia; Central African Republic; Chad; Comoros; Congo; Democratic Republic of Congo; Djibouti; Eritrea; Guinea-Bissau; Kyrgyzstan; Lesotho; Liberia; Mauritania; Mongolia; Namibia; Samoa; São Tomé and Principe; South Sudan; Sierra Leone; Solomon Islands; Somalia; Tajikistan; and Yemen. Beyond the search criteria, various reasons could explain why these countries were not included, such as a lack of research stations, remote access, limited agricultural production, amongst other factors (see discussion).

Spatial unit of analysis

Geographic scales of plot, farm, landscape, district, and region, as well as social scales of individual, household, and village were differentiated following Randall and James [23]. The scale of 'plot' referred to studies that compared specific in-field interventions (e.g. different rates of organic farmyard manure fertiliser application or tillage regimes), whereas 'farm' compared results across a number of farms. Many studies that compared across larger areas could also be considered landscape scale studies. In some cases it was not possible to discern aspects of the spatial scale, because studies did not state whether interventions were replicated within single or on multiple farms [23].

Most studies were conducted at the plot scale (42 %, $n = 317$) or farm scale (31 %, $n = 233$), followed by regional (10 %, $n = 73$), landscape (8 %, $n = 62$), and district scales (6 %, $n = 41$). Many studies were performed across various sites and various scales; for instance, 221 studies had multiple study sites. Eleven studies involved cross-country analyses, seven compared two countries, two compared three, one compared four, and one compared five. Two studies were cross-continental, assessing carbon sequestration rates in no-tillage soils in tropical Brazil and Madagascar [43], and agroforestry and fallow systems in Cameroon, Madagascar, Tanzania, Indonesia, and Laos [44]. Ninety-two per cent of studies used geographic, rather than social, scales of organisation.

Farm typology

Figure 7 shows the number of studies according to farm typology and irrigation type, adapted from the categorisation of Dixon, Gulliver and Gibbon [45]. Research stations, which include working farms, (Table 2) comprised almost half of studies (48 %, $n = 358$). These studies usually did not state whether they focused on irrigated or rain-fed crops. Smallholder farms comprised a quarter of studies (24 %, $n = 176$). Twelve per cent ($n = 16$) of these were rain-fed, only 4 % were irrigated, and the remainder

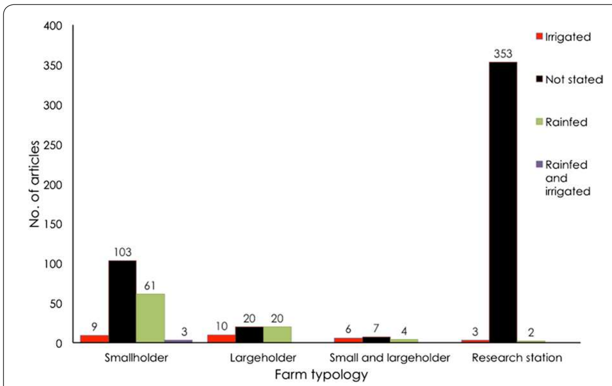


Fig. 7 Number of studies according to farm type and irrigation method. The *figure* shows studies have been predominantly conducted in research stations, followed by rain-fed smallholder farms. Studies of smallholder farms were predominantly located in India ($n = 27$), China ($n = 15$), Ethiopia (n = 14), Brazil ($n = 12$), and Zimbabwe ($n = 11$). The majority of large or commercial farms were predominantly in Brazil ($n = 11$), China ($n = 7$), India, Mexico and South Africa (ea. $n = 6$). The small number of studies conducted in large-scale farms could be reflective of the regions included in the study

of studies did not state irrigation techniques. Large-scale and commercial farms constituted the smallest proportion of studies (7 %, $n = 50$). Very few studies combined assessments on both small and large farms (2 %, $n = 17$). 145 studies did not state the type of farm.

Ecosystem service

The systematic map differentiated between broad categorisations of ecosystem services and 16 subtypes, based on the Millennium Ecosystem Assessment categorisation [6] (see protocol [32] for rationale). Categories are non-exclusive, such as soil regulation and nutrient cycling. Supporting services were measured in 55 % ($n = 591$) of studies, regulating services 33 % ($n = 353$), provisioning 9 % ($n = 101$), and cultural services 3 % ($n = 32$) (non-exclusive categories). Biodiversity was studied more than pest regulation and pollination services. Spiritual and symbolic value often appeared in conjunction with studies of medicinal and aromatic plants, while only five studies measured tourism as a cultural service (Table 3). One-third of studies (36 %, $n = 266$) measured ecosystem services in combination with one another, most frequently combining supporting and regulating services (85 %, $n = 22$). Most studies (92 %, $n = 689$) measured one or two ecosystem services, while studies of three or more ecosystem services only constituted 8 % ($n = 57$). The mean number of ecosystem services measured per study was 1.45 ± 0.85. Figure 8 indicates the number of ecosystem services measured, plotted against the duration of studies.

Table 2 Number of studies on in-field assessments of ecosystem services conducted on farms in research stations, of the ten most frequently cited countries

Rank	Country	No. studies	Common research stations			
1	China	115	Changshu agro-ecological experiment station affiliated to Institute of Soil Science, Chinese Academy of Sciences, Changshu, Jiangsu Province	Key agro-ecological experimental station of Fengqiu State, Fengqiu county, Henan Province	Luancheng Agro-Ecosystem Experimental Station, Chinese Academy of Sciences, Hebei Province	Shangzhuang Research Station, China Agricultural University, Beijing Province
2	India	77	Indian Agricultural Research Institute (IARI) Farm, New Delhi	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Centre, Patancheru, near Hyderabad	Central Rice Research Institute, Cuttack	Vivekananda Institute of Hill Agriculture in the Indian Himalayan at Hawalbagh, Uttarakhand
3	Brazil	62	Empresa Brasileira de Pesquisa Agropecuaria research station (EMBRAPA), [3 sites—Manaus, Amazonas, and Rio Grande do Sul and North-Goiânia]	Experimental station of Agronomic Institute of Paraná (IAPAR), district of Londrina, Paraná State	Research centre Fundação Centro de Experimentação ePesquisa (FUNDACEP), near the city of Cruz Alta, Rio Grande do Sul State	Research station of MARS Center of Cocoa Science, Itajuıpe, southern region of Bahia
4	Mexico	23	El Batán research station, near Lake Texcoco, Central Mexico	Centro de Investigaciones Agrıcolas del Noroeste (CIANO), near Ciudad Obregon, State of Sonora	Rio Bravo experimental site, Northern Tamaulipas	Campus of Biological Sciences of the University of Yucatan (CBS) at Xmatkuil, Mexico
5	Philippines	8	International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines	Guimba, Nueva Ecija Province, Phillipines	Laguna, Philippines	Leyte, Philippines
6	Nepal	7	Nepal Agricultural Research Council (NARC) at Lumle and experimental farm of the Institute of Agriculture and Animal Science (IAAS) of Tribhuvan University at Rampur, Chitwan, Nepal	Hattiban Station, Nepal Agriculture Research Council (NARC), Kathmandu valley, Nepal	Institute of Agriculture and Animal Sciences (IAAS), Tribhuvan University, Chitwan Valley, Inner Terai of Nepal	Rampur, Chitwan, Terai Plains of Nepal
7	Zimbabwe	6	Henderson Research Station Mashonal and Central Province, Zimbabwe	Domboshawa Training Centre, Zimbabwe	West of Chipinge Town, Zimbabwe	Harare, Zimbabwe
8	Cameroon	5	ESA Project experimental sites in the villages of Winde, Zouana, Cameroon	Ngomedzap, Bakoa, Obala, Talba and Kedia, Cameroon	Mbalmayo, Cameroon	Yaounde, Cameroon
9	Thailand	5	Khao Hin Sorn Development and Study Centre,Cha Cherng Sao Province, Thailand	International Training Center for Agricultural Development, Khon Kaen, Thailand	Khon Kaen Province, Thailand	Bangkok, Thailand
10	Ghana	4	Atewa Range Forest Reserve and Adjeikrom, Ghana	Forestry Commission of Ghana, Legon, Western Ghana	Sefwi Wiawso, Ghana	Kwadaso, Ghana

The table shows commonly cited research stations, and indicates most studies are published in China, India, Brazil, and Mexico

Table 3 Number of articles per ecosystem service

Ecosystem service	No.	%	Total %	Total no.
Supporting				
Carbon storage or sequestration	282	26.2	54.9	591
Nutrient cycling	183	17.0		
Biodiversity	81	7.5		
Pest regulation	45	4.2		
Regulating				
Soil regulation	200	18.6	32.8	353
Pollination	48	4.5		
Water regulation	105	9.8		
Provisioning				
On-farm non timber forest products	35	3.3	9.4	101
Medicinal and aromatic plants	26	2.4		
Fuel wood	23	2.3		
Building material	17	1.6		
Cultural				
Spiritual or symbolic value	11	1.0	3.0	32
Aesthetic or bequest value	6	0.6		
Educational value	6	0.6		
Recreational value	6	0.6		
Tourism	3	0.3		
Total	1077	100	100	1077

The total number of services (1077) is greater than the number of studies, because many assessed ecosystem services under more than one category

Conservation land management interventions

In total, 19 categories of conservation land management were measured (Table 4). Top interventions included use of organic fertiliser (24 %, $n = 358$), tillage (23 %, $n = 350$), agroforestry involving multipurpose and multistorey cropping and home gardening (9 %, $n = 129$), and seven methods of water conservation (7 %, $n = 98$). Other practices included: crop rotation; fallowing; cover cropping with legumes or shaded patches; mosaic management including the maintenance of wild vegetative patches on farms; set aside areas and buffer strips; restoration including re/afforestation; five methods of weed management including mechanical, disc harrowing, herbicide, cover cropping and mulching; integrated pest management; pollination management; two types of mulching using crop residues and plastic film; erosion control using terracing and slope re-vegetation; and intercropping with legumes and cereals. The remaining studies involved passive management, rather than active, such as maintaining biodiversity on farms, fire management, and retaining termite mounds within farms to promote nutrient cycling.

The link between management strategy and objective or outcome was not necessarily uniform nor simple. For example, crop residues could be used for mulch, organic fertiliser and weed management. In addition, a number of management practices were frequently adopted in conjunction with one another (e.g. combining leguminous cover crops with minimal tillage). Within studies, conservation land management strategies were compared to other practices, for example organic and inorganic fertiliser, organic and inorganic mulching, integrated pest management and insecticides, mechanical weed control and herbicides, or mosaic and monocropping. Figure 9 plots the ten most frequent land management interventions measured against the year of publication.

Soil fertilisation

Organic fertiliser, composed of eight possible products, ranked as the most commonly assessed intervention (24 %), frequently studied in Far East ($n = 88$) and South Asia ($n = 60$). Farmyard manure sourced from cattle, poultry or pigs comprised 43 % ($n = 154$). Other products used included: urea (9 %, $n = 71$); crop residues (8 %, $n = 66$); leaf manure; lime; dolomite; ash and coal; bio-char; vermin-culture and waste; biogas slurry; vinasse by-products from the sugar industry; distillery waste; and household or slaughter-house waste (Fig. 10). Crop residues commonly incorporated leaves, straw and stalks remaining on the soil surface from the previous season's crops. Composites included: rice straw; wheat straw; groundnut cake; rapeseed cake; cottonseed cake; leaf litter and water hyacinth. However, studies that included conventional practices of inorganic fertiliser (e.g. NPK, N, P_2O_5, K_2O and dicyandiamide) surpassed those with organic fertiliser practices (55 %, $n = 437$, and 45 %, $n = 358$, respectively) (Fig. 10). Studies also measured the impact of mulching on soil organic matter accumulation and nitrogen mineralisation [46], soil water content [47], microbial communities [48] and water stable aggregates [49],

Tillage

Ten methods of tillage were often measured in combination with one another, comprising 23 % of studies. Figure 11 indicates that no-till was the most frequently assessed tillage method (40 %, $n = 141$), followed by measurements of single conventional tillage practices as comparators to other tillage practices (32 %, $n = 111$). The other practices assessed and their proportion of studies were as follows: disk harrow tillage (9 %, $n = 30$); minimum tillage including ripping and direct seeding (5 %, $n = 16$); ridge and basin tillage (4 %, $n = 15$); rotivar tillage ($n = 15$, 4 %); mouldboard; base and country plough tillage (2 %, $n = 8$); double conventional tillage (2 %, $n = 8$); deep chisel and shallow till (each 0.9 %, $n = 3$).

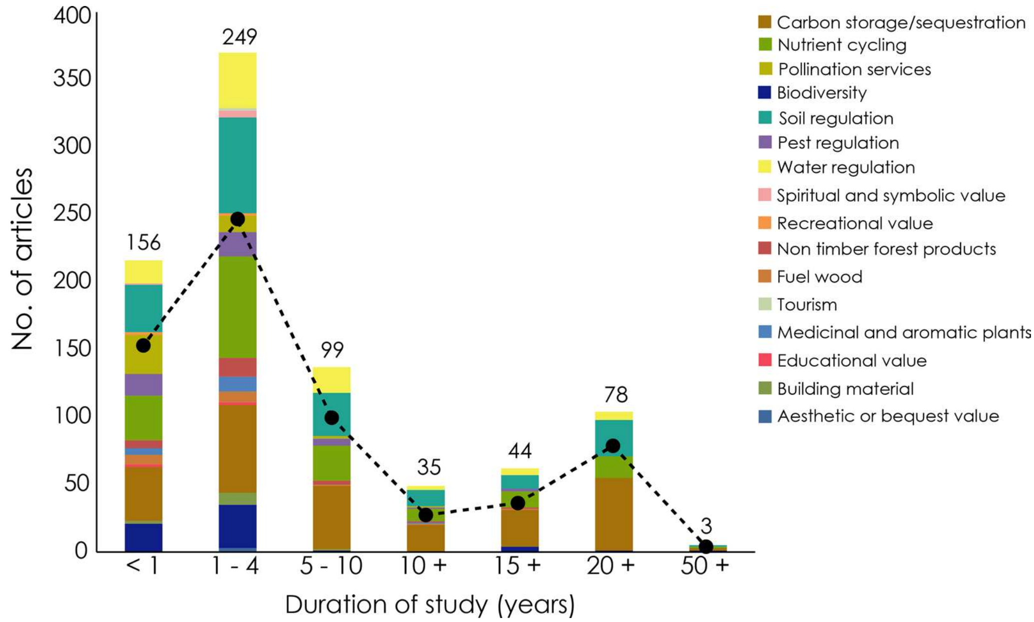


Fig. 8 Ecosystem services measured and duration of studies. The *figure* shows nutrient cycling was mostly studied 1 to 4 years. Of 44 studies measuring pollination, most were less than one year (66 %, $n = 29$) or 1 to 4 years (27 %, $n = 12$). Most studies monitoring biodiversity on farms were conducted in less than 4 years (65 %, $n = 53$), as were pest regulation (76 %, $n = 34$) and pollination (85 %, $n = 41$). Carbon sequestration and storage made up the largest proportion of long-term studies (i.e. 20 +/50 + years) (51 %, $n = 56$), together with nutrient cycling (16 %, $n = 17$) and soil regulation (26 %, $n = 28$). The *dotted line* indicates the number of articles, which is less than the total as many studies measured more than one service

Agroforestry

Agroforestry interventions accounted for 129 of the studies, and included multistorey cropping for multiple purposes: food; fruit; fodder; ornaments; timber; shade; fuel wood; cosmetics; teeth brushing; oil; animal hide tanning; religious purposes; latex; soil enhancement and nitrogen fixation (e.g. leguminous trees), live fencing and windbreaks; and erosion control. Common tree crops included: coffee ($n = 63$); cacao ($n = 30$); banana including false banana (enset) ($n = 23$); tea ($n = 15$); guava ($n = 8$); mangos; mangosteens; rubber; oil palm; and Barbados nut (ea. $n = 6$). Fruit crops comprised 61 % of agroforestry crops. Twenty studies also evaluated the multifunctional role of home-gardens [50], in which both deciduous and evergreen trees were included. Additional file 8 lists 65 of the agroforestry tree crops included in the systematic map and their uses.

Crop types

Crops and regions

A total of 72 types of crops were studied (summarised in Table 5). In line with a hypothesised trend stated in the protocol, most studies assessed annual crops (62 %, $n = 462$) instead of perennial crops (25 %, $n = 190$). Staples were frequently studied: maize (18 %, $n = 285$), wheat (12 %, $n = 183$), and rice (10 %, $n = 152$). Other major crops studied included tree crops, soybeans, coffee, beans, sorghum, cotton and finger/pearl millet. Despite the extent of global cultivation, our review identified a limited number of studies in palm oil, tobacco and rubber; although this result may be due to countries excluded, such as Indonesia (*see* [51]). When compared to the global area of cultivated crops, the proportion of studies looking at rice most similarly reflected the proportion of land cultivated globally (Table 6).

Cereal grains constituted 45 % ($n = 692$) of studies, predominantly in Far East Asia ($n = 221$), South Asia ($n = 167$) and South America ($n = 101$). The majority of studies on tree crops (21 %, $n = 52$) and legumes (24 %, $n = 46$) were in South Asia. Fruit crops ($n = 31$) and tubers ($n = 16$) were most frequently measured in East Africa. Assessments of vegetables were less common, and predominantly in South Asia ($n = 14$) and East Africa ($n = 18$). Soybean was most frequently studied in South America (44 %, $n = 35$), likely because Brazil is the world's second top producer (65.9 m metric tonnes/annum), following the US [54]. Coffee was most frequently measured in East Africa (28 %, $n = 20$), including top producing countries of Ethiopia and Uganda. No studies were identified assessing *Adansonia digitata* (baobab), *Moringa oleifera L.* (moringa) and *Vitellaria paradoxa* (shea tree), even though these are increasingly

Table 4 Conservation land management interventions studied

Group	Rank	Conservation land management intervention	No.	%
Organic fertiliser (23.8 %, 358)	1	Farm yard manure (pig, poultry, cattle)/compost	154	10.2
	2	Urea	71	4.7
	3	Crop residues	66	4.4
	4	Leaf/green manure	27	1.8
	5	Lime (incl. dolomite)/ash (coal and volcanic soils)	14	0.9
	6	Biochar	13	0.9
	7	Vermiculture	8	0.5
	8	Waste (slaughterhouse/human effluent/biogas slurry/vinasse/distillery hh waste)	5	0.3
Tillage (23.3 %, 350)	1	No till	141	9.4
	2	Single conventional tillage	111	7.4
	3	Disk harrow/plough	30	2.0
	4	Minimum (incl. ripping and direct seeding)	16	1.1
	5	Ridge/basin	15	1.0
	6	Rotivar	15	1.0
	7	Mouldboard/base/country plough	8	0.5
	8	Double conventional tillage	8	0.5
	9	Shallow	3	0.2
	10	Deep chisel	3	0.2
Agroforestry (8.6 %, 129)	1	Multipurpose tree species with multistorey cropping	109	7.3
	2	Homegardens	20	1.3
Water conservation (6.5 %, 98)	1	Other water conservation techniques	28	1.9
	2	Maintaining raised beds, tied ridges and ditches	24	1.6
	3	Alternative wet—dry rice irrigation	18	1.2
	4	Partial root zone	9	0.6
	5	Intermittent submergent irrigation (shallow water for pre- and middle tillering stage, field sun drying for late tillering stage, then shallow water again until ripening stage)	9	0.6
	6	Drip irrigation	6	0.4
	7	Wastewater/treated sewage effluent (TSU)	4	0.3
Weed management (2.8 %, 42)	1	Herbicides/fungicides	22	1.5
	2	Mechanical	14	0.9
	3	Crop residues	4	0.3
	4	Wide seedling spacing	1	0.1
	5	Burning	1	0.1
Cover crops (5 %, 75)	1	Legumes	50	3.3
	2	Shaded patches	25	1.7
Pest management (2.5 %, 38)	1	Insecticide	22	1.5
	2	Integrated, including neem	16	1.1
Mulching (1.4 %, 21)	1	Surface crop residue retention	17	1.1
	2	Plastic Film Mulched (PFM)	4	0.3
Fallowing (5.6 %, 84)	1	Dry	79	5.3
	2	Wet	5	0.3
Erosion control (1.3 %, 20)	1	Terracing	11	0.7
	2	Revegetating slopes	9	0.6
Restoration (2.8 %, 42)	1	Re/afforestation [incl. some rotational woodlots (three studies)]	34	2.3
	2	Other	8	0.5
Passive interventions (3.1 %, 46)	1	Maintaining biodiversity on farms	16	1.1
	2	Fire management including supporting natural burning regimes	13	0.9
	3	Carbon sequestration	12	0.8
	4	Nutrient cycling by maintaining termite mounds within cultivated areas	5	0.3

Table 4 continued

Group	Rank	Conservation land management intervention	No.	%
Pollination management (1.6 %, 24)	1	Hand pollination, camel hair brush, glass rod tapered, match stick or provision of beehives	24	1.6
Mosaic/matrix management (4.5 %, 67)	1	Wild/natural vegetation within/adjacent farmlands	57	3.8
	2	Set aside areas such as buffer strips, alleys, hedgerows or field margins	10	0.7
Crop rotation (6 %, 90)	1	Relay cropping/shifting cultivation	90	6.0
Intercropping (1.3 %, 20)	1	Push pull systems, legumes and cereals/fruit trees, N fixing trees with cardamom	20	1.3
Total			1504	100

The overall total ($n = 1504$) is more than 746, because some studies assessed more than one conservation land management intervention

hh household

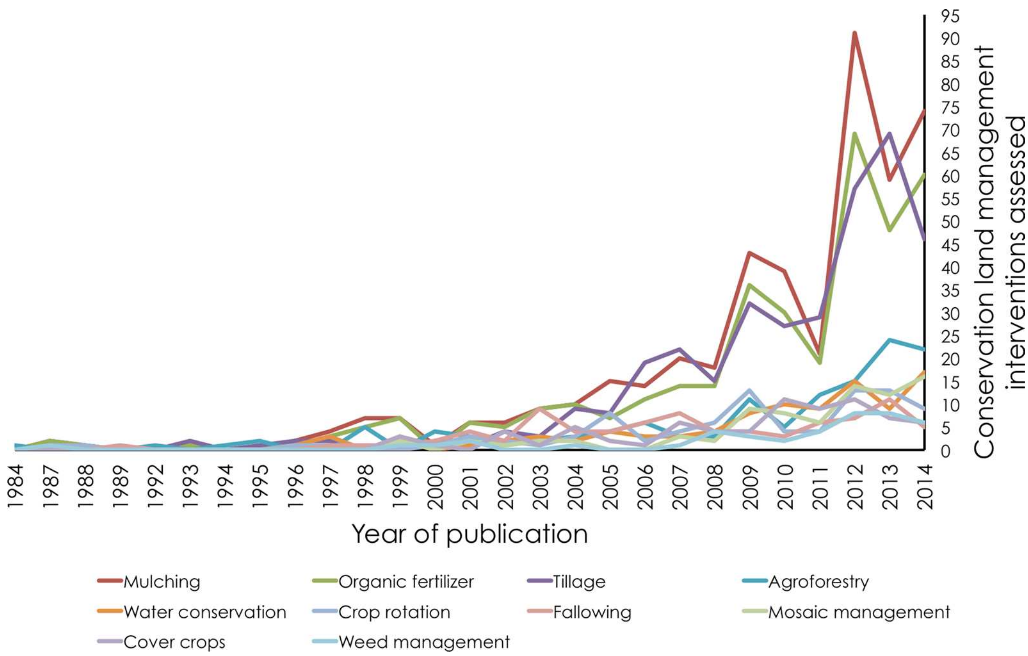


Fig. 9 Ten most frequently studied conservation land management interventions (1984–2014). The *figure* shows notable increases in the absolute number of studies occurred between 2008–09 and again between 2011–12. In particular, from 2011 to 2012, the number of assessments of mulching increased c. 4.5-fold (21–91), organic fertiliser increased c. threefold (19 to 69) and studies measuring the impact of alternate tillage regimes almost doubled (29–57)

marketed internationally as health foods, providing alternative livelihoods for smallholder farmers.

Crops and interventions

Most studies assessing the impact of tillage and crop rotation were in wheat and maize cropping systems. Agroforestry was the most prevalent in tree crop and coffee production systems, and water conservation practices were most frequently measured in rice cropping systems. Biodiversity was most frequently studied in sites with coffee, other tree crops, or maize. Crop rotation most often arose in studies of maize, followed by wheat and soybeans (Table 7). Additional file 9 tabulates all the conservation land management and interventions and ecosystem service measured.

Indicators to measure on-farm conservation interventions

One hundred and seventeen indicators were measured (Table 8). Indicators were identified using the description given in studies. Some indicators overlap (e.g. yield could be categorised under economic indicators, above ground biomass could also refer to yield), or be closely associated (e.g. Soil Organic Carbon and Total Carbon). Unsurprisingly, most commonly measured indicators are strongly associated with crop productivity, (i.e. Soil Organic Carbon (SOC), macronutrients, yield, bulk density and pH).

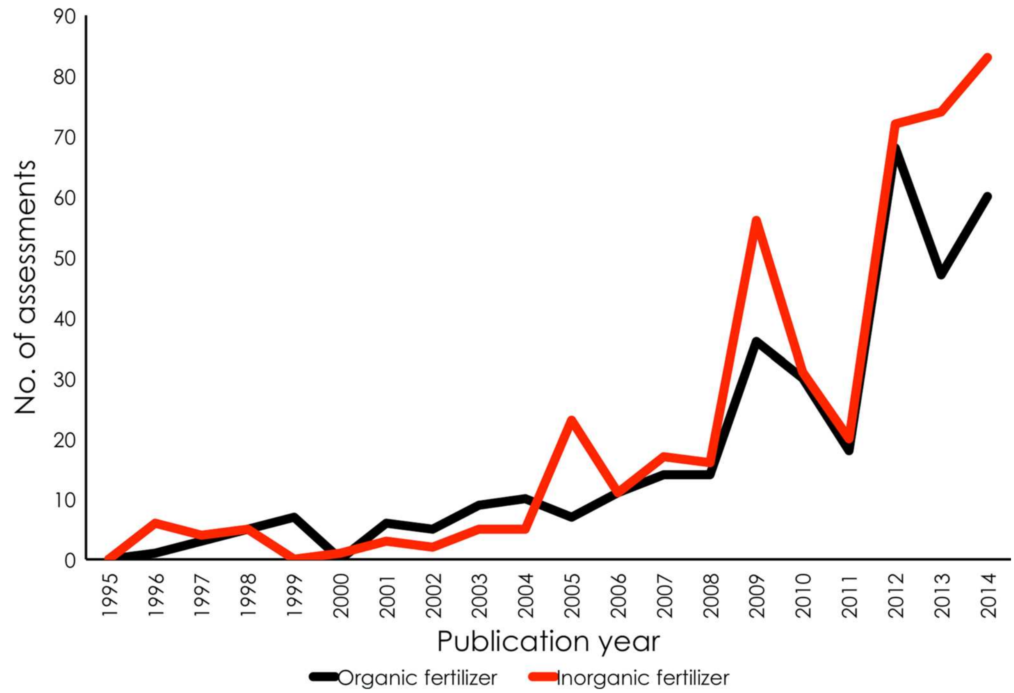


Fig. 10 Number of studies/year measuring organic and inorganic fertiliser application (1995–2014). The *figure* shows that in the last two decades since 1995 there has been an increase in studies in both inorganic and organic fertiliser. However, inorganic fertiliser has been studied more frequently studied that organic

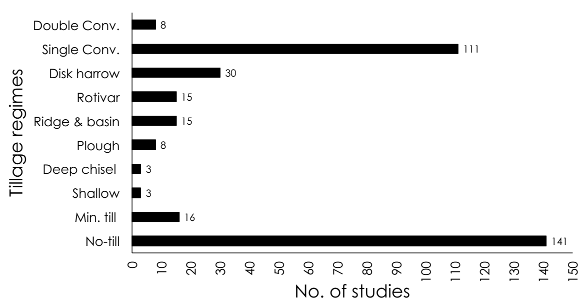


Fig. 11 Number of studies that assessed the impact of tillage regimes

Out of 746 studies, 73 % ($n = 544$) measured chemical indicators—mostly SOC, followed by N, P, K, pH, Total C, CO_2, Mg, N_2O and NO_3. Physical indicators were measured in 53 % ($n = 398$) of studies - mostly bulk density, soil texture/particle size, water holding capacity/soil moisture retention, soil type, temperature, soil porosity, runoff and soil loss (for leaching), water use efficiency, water infiltration rates and altitude. Biological indicators were measured in 73 % of studies ($n = 546$)—mostly yield, community diversity/richness and abundance, followed by microbial biomass content, below-ground biomass, stem density/diameter, litter, fruit set, survival rate of trees and crop height. Social indicators were measured in 13 % of studies ($n = 96$), primarily perceptions of pest incidence, followed by fuel wood supply and usage, medicinal and aromatic plants, water quality and soil regulation. Other variables described the farming context, such as household size, village size, months of food security, land tenure and presence of farmers associations to access information and funds. Twelve per cent ($n = 93$) measured economic indicators, mostly income, farm inputs, labour days, and farm size and livestock ownership. Indicators of willingness-to-pay or opportunity cost were not included, given that purely economic valuation studies were excluded from the review.

Taxonomic indicators

Of the 203 studies measuring types of taxonomic groups [following Randall and James (2012) [23]; (Fig. 12)], plants were most commonly studied (32 %, $n = 66$), followed by invertebrates (non-pollinating) (29 %, $n = 59$) and pollinators (22 %, $n = 44$). Very few studies measured birds and mammals, while two studies did not mention which taxonomic indicators were used. Studies measuring mammals included one study of large terrestrial ungulates, carnivores, large rodents, armadillos and primates in cacao agro-forests in southern Bahia, Brazil [55], a study assessing shrews in a sugarcane plantation in the

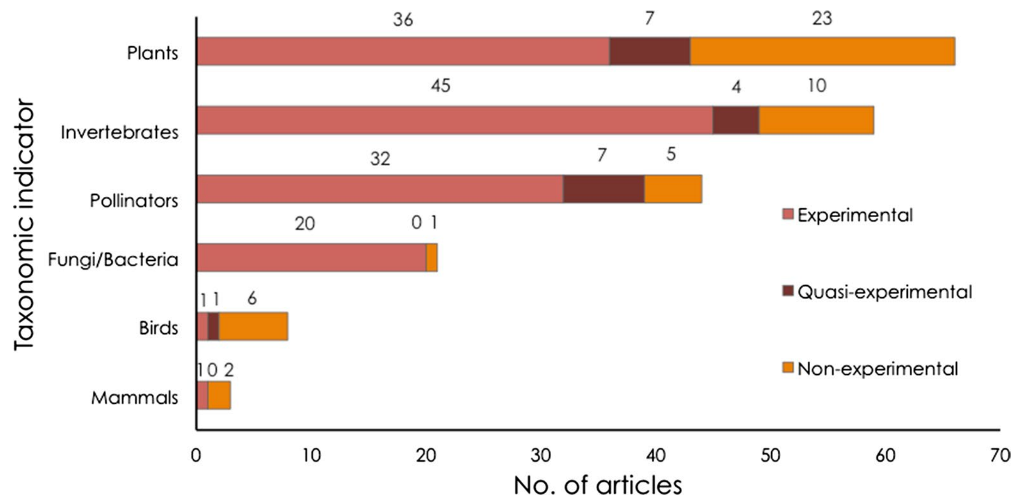


Fig. 12 Number of articles for each taxonomic indicator. Exclusion of biomes in the search, including pastures, grasslands, mangroves, fresh water and marine systems, may have led to some bias against taxonomic groups associated with these systems. The *figure* shows most assessments consider no-, single- and double-conventional tillage. (*Conv* Conventional tillage, *Plough* Includes mouldboard, base, country plough)

Table 5 Crop group categorisation used in the study, and 72 crops that were studied

Crop group	Crops included in group
Cereal grains	Barley, oats, rice, maize, wheat, rapeseed, sorghum, millet, safid muesli, teff/annual bunch grass
Fruits	Watermelon, peach, guava, apple, mango, pineapple, lemon, orange, plantain, grape, banana, pear, plum
Legumes	Chickpea, soya bean, mung bean, faba bean, jack bean, french bean, locust bean, alfalfa, hairy and milk vetch, cowpea, peanut/groundnut
Vegetables	Gourd, aubergine, pumpkin, cucumber, chilli, green pepper, lettuce/chicory
Grasses	Sugarcane, caster, agave, tifton, napier, grass pea, guina grass, italian ryegrass, pangola grass, congo grass, caribean stylo, beard grass
Tubers	Sweet potato, potato, carrot, cassava, yam

Lowveld of Swaziland [56], and a study on large mammals including buffalo, eland, and hartebeest in Zambia [57]. Various studies also measured changes in dynamics of functional groups in bird and insect communities, including decomposers (e.g. termites, earthworms), phytovores (e.g. weevils), carnivores and frugivores (e.g. birds) [58], tunneller and roller species [59], and pollinators, including stingless bees, solitary wasps, birds, bats and bumblebees [60]. Manipulative or experimental designs were the most common design for all animal taxa (67 %, $n = 135$) except for birds, where 75 % ($n = 6$) of studies were non-experimental. Studies of plants had a comparatively larger proportion of non-experimental designs compared to other taxonomic groups (39 %, $n = 23$), particularly study systems with agroforestry, reforestation, home gardens or smallholder agricultural mosaics.

Indicators used to measure key ecosystem services

Water regulation Studies predominantly measured water conservation practices to reduce water losses from seepage, percolation and evaporation, and to preserve soil moisture (22 %, $n = 47$). Many studies also looked at how minimum till (19 %, $n = 37$), fallowing (5 %, $n = 10$)

Table 6 Three most frequently studied crops compared to area cultivated globally

Most frequently studied crops	% studies	No. studies	% of global cultivated area[a]	2014 global acreage (m. ha)	Source
Maize (*Zea mays*)	18.5	285	12.3	184	International service for the acquisition of agri-biotech applications, 2014
Rice (*Oryza sativa L.*)	*11.9*	183	*10.7*	160.6	US Dept Agric, Statistica 2015
Wheat (*Triticum*)	9.9	152	14.3	215	CGIAR 2015

The table shows the proportion of studies on three staple crops in relation to the proportion of land cultivated globally (shown in italic)

[a] Total cultivated area of crops is 1500 mha [3, 52, 53]

Table 7 Summary of crops vs. conservation land management interventions studied

Crop	Organic fertiliser	Tillage	Crop rotation	Agroforestry	Water conservation
Beans	15	8	10	12	6
Coffee	10	1	2	24	2
Cotton	12	14	9	2	7
Maize	107	118	60	23	25
Millet	17	7	7	6	6
Tree crops	14	8	5	58	6
Rice	67	41	23	9	36
Sorghum	16	9	5	4	4
Soybean	29	45	27	1	7
Wheat	90	73	47	6	35

Table 7 illustrates tillage and organic fertiliser has been most commonly studied in maize ($n = 171$, $n = 107$), while water conservation has been mostly commonly studied in rice ($n = 36$) and wheat ($n = 35$)

[61], cover cropping (4 %, $n = 8$) and mulching (3 %, $n = 5$) affected water infiltration and runoff [62]). Water regulation was commonly studied in combination with soil regulation, while conservation techniques included micro-dams and furrows, dug out ponds, sub-surface runoff harvesting tanks, rooftop rainwater harvesting system, stone bunds, dense runoff collector trenches, draining to sinks, dam maintenance, abandonment of post-harvest grazing, irrigation canals. One hundred and five studies measured indicators of water regulation (Fig. 13).

Cultural services Most studies of cultural services considered the utilisation and maintenance of wild and cultivated plants on farms that provided biological materials used for medicinal, ritual, edible, ceremonial, timber, ornamental and other purposes [63]. Studies described how the management of biodiversity supports beliefs and cultural continuity [64], and fosters communities' social fabric through the sharing of resources [65]. Other studies measured the aesthetic value of biodiversity on farms, such as birds in isolated trees or open areas outside the forest [66]. Only 32 studies measured these indicators of cultural services (Fig. 14).

Pollination services Studies measured the effects proximity of fields to semi-native habitats have on insect community diversity and abundance [15, 70, 71], the impact of plant types [72] or landscape effects on pollinator populations and activity [73], or the placement of beehives or trap nests in fields [74]. A total of 48 studies looked at pollination services (Fig. 15).

Carbon regulation Carbon storage and sequestration, included in 282 studies, often measured SOC content [75], and carbon pools in soil, soil litter or in biomass [76]. Carbon regulation services were commonly associated with practices of organic fertiliser application, crop rotation, reducing or eliminating soil tillage [75, 76]. Interestingly, only one study assessing carbon regulation measured perceptions of soil organic carbon (Fig. 16).

Outcomes on ecosystem service and yield

The reported overall outcome (or effect) of management strategies ecosystem service provision and on yield was examined using the authors' own conclusions of the studies, following Milder et al. (2014) [77]. In addition to ecosystem service provision, yield was recorded given the association with income, livelihoods and food security, and thus the high value land managers may place on maximizing when choosing land management strategies to implement. Recording both factors is useful for future analysis in assessing benefits and trade offs of conservation land management strategies. Independent analysis of the studies results is outside the scope of a systematic map, but documenting the claims made regarding yield and ecosystem service outcomes would constitute a useful area for a future systematic review incorporating statistical analysis. Of the studies that explicitly stated the outcomes of interventions:

- on ecosystem services and yield ($n = 181$) (often referred as 'win–win' [78]), 57 % reported dual benefits of ecosystem service and yield improvements;
- on ecosystem services ($n = 671$), 63 % reported an improvement, 28 % found mixed outcomes, 5 % reported no change, and 4 % reported a decline in ecosystem services as a result of the intervention (Table 9); and
- on yield ($n = 337$), 66 % reported an improvement, 22 % reported a mixed outcome, 7 % found no impact, and 5 % reported a decline.

Mixed outcomes were reported in 39 studies (12 %). Very few studies identified trade-offs between conservation land management practices. However, five studies (2 %) found an improvement in ecosystem service but decline in yield and three studies (1 %) showed an

Table 8 Indicators measured in studies

Rank	Chemical indicators	No	%	Physical indicators	No	%	Biological indicators	No	%	Social indicators	No	%	Economic indicators	No	%
1	Soil organic carbon (SOC)	333	17.4	Bulk density	154	20.0	Yield[a]	273	39.5	Pest incidence	23	17.6	Income	54	35.3
2	Nitrogen (N)	310	16.2	Soil texture/particle size	136	17.7	Diversity/richness	109	15.8	Fuel wood use	18	13.7	Farm inputs	34	22.2
3	Phosphorus (P)	230	12.0	Water holding capacity/ soil moisture retention	98	12.7	Community abundance	80	11.6	Medicinal value	14	10.7	Labour days	23	15.0
4	Potassium (K)	197	10.3	Soil type	97	12.6	Microbial Biomass Content (MBC)	37	5.4	Water quality	12	9.2	Farm size	22	14.4
5	pH	189	9.9	Temperature	51	6.6	Below ground biomass	33	4.8	Perception of soil quality (SOC)	9	6.9	Livestock ownership	7	4.6
6	Total carbon (TC)	135	7.0	Soil porosity	33	4.3	Stem density/diameter	31	4.5	HH size/type	8	6.1	Cropping intensity	5	3.3
7	Carbon dioxide (CO2)	82	4.3	Runoff and soil loss (for leaching)	29	3.8	Litter	24	3.5	Edible wild species	7	5.3	Alt. livelihoods	3	2.0
8	Magnesium (Mg)	41	2.1	Water use efficiency (WUE)	29	3.8	Fruit set	23	3.3	Ethnic group	6	4.6	Shade	2	1.3
9	Nitrous Oxide (N20)	36	1.9	Water infiltration rate	21	2.7	Survival rate of trees	12	1.7	Village	6	4.6	Market access	1	0.7
10	Nitrate (NO3)	34	1.8	Altitude	15	2.0	Crop height	11	1.6	Food security	5	3.8	Credit	1	0.7
11	Boron (B)	32	1.7	Turbidity/water stable aggregates	12	1.6	Species mass, sex, age	9	1.3	Recreational value	5	3.8	Stumpage fee	1	0.7
12	Heavy metals (e.g. Cd,Cu,Pb,Cr,Zn,Ni)	30	1.6	Base saturation	12	1.6	Seedling density	8	1.2	Ornamental value	5	3.8			
13	Chlorine (Cl)	30	1.6	Electric conductivity (for solids)	11	1.4	Basal stand	7	1.0	Farmer's assoc	3	2.3			
14	Methane (CH4)	29	1.5	Soil colour	10	1.3	Flower visitation rate	7	1.0	Sacred sites	2	1.5			
15	Dissolved Organic Carbon	25	1.3	Soil depth	10	1.3	Macro-faunal activity	7	1.0	Climate regulation	2	1.5			
16	Soil enzymes (e.g. acid phosphatase)	22	1.2	Slope gradient	9	1.2	Species body/tail/wing length	6	0.9	Educational value	2	1.5			
17	C:N ratio	21	1.1	Rainfall	8	1.0	Fine root production	5	0.7	Land tenure	2	1.5			
18	Cation exchange capability	21	1.1	Distance to natural areas	7	0.9	Weed growth	3	0.4	Ritual artefacts	1	0.8			
19	Calcium (Ca)	17	0.9	Light intensity/radiation	6	0.8	Above ground biomass	3	0.4	Fodder	1	0.8			
20	Electric conductivity (liquids) (EC)	15	0.8	Humidity/water vapour	4	0.5	Rhizodeposition	2	0.3						
21	Ammonium (NH4-)	12	0.6	Erosion control	4	0.5	Leaf area index	2	0.3						
22	Salinity/sodium/salt (NaCl)	11	0.6	Evaporation/transpiration	3	0.4									
23	Nitrogen use efficiency (NUE)	9	0.5	Groundwater depth	3	0.4									
24	Ammonia (NH3)	7	0.4	Aspect	2	0.3									
25	Aluminium (Al)	7	0.4	Surface flow	2	0.3									

Table 8 continued

Rank	Chemical indicators	No	%	Physical indicators	No	%	Biological indicators	No	%	Social indicators	No	%	Economic indicators	No	%
26	Soluble/crude protein or starch, carbohydrates	7	0.4	Patch size	2	0.3									
27	Hydron (H +)	6	0.3	Respiration	1	0.1									
28	Polyphenol content, lignin, cellulose	5	0.3												
29	Sulphur (S)	5	0.3												
30	Total soluble sugar (CnH2nOn)	5	0.3												
31	Iron (Fe)	4	0.2												
32	Exchangeable sodium % (ESP)	4	0.2												
33	Sulfate (SO4)	3	0.2												
34	Amino sugars	2	0.1												
35	Residual selenium	1	0.1												
36	Cholorphyll	1	0.1												
37	Dissolved oxygen (DO)	1	0.1												
TOTAL		1919	100		769	100		692	100		131	100		153	100

The overall totals are more than 746 because all studies assess multiple indicators

TC total carbon including inorganic, Walkley–Black carbon, Labile carbon, particulate organic carbon, total organic carbon, *HH* household

[a] Yield was typically measured in kg/ha)

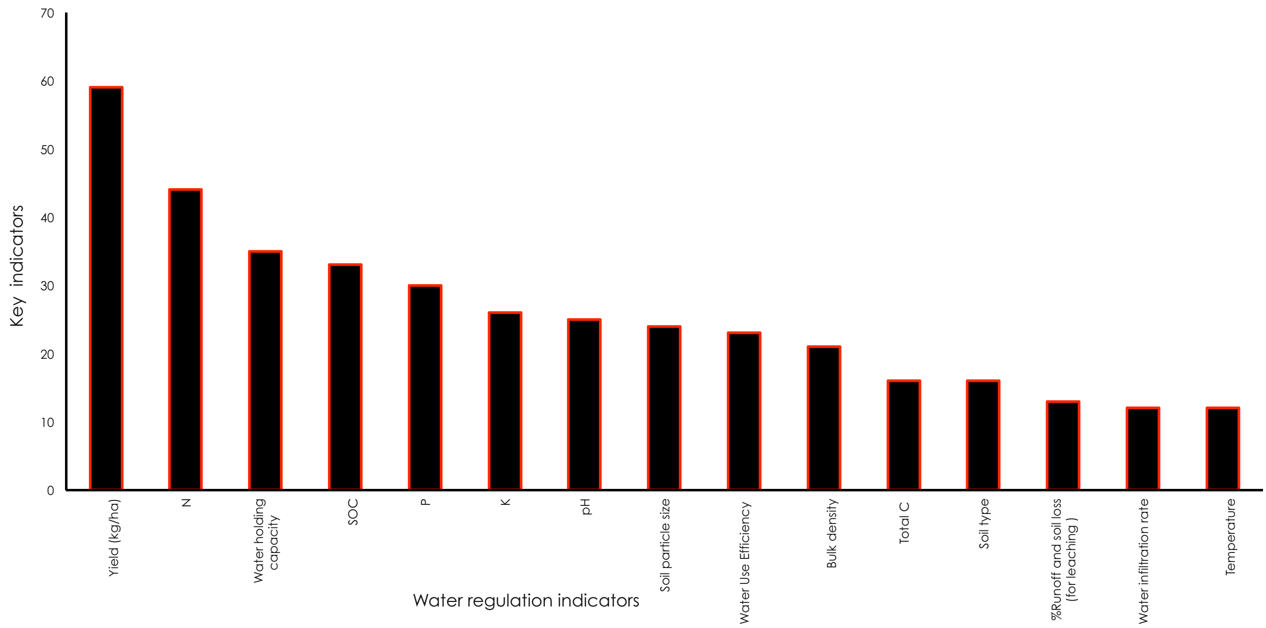


Fig. 13 Water regulation indicators. Eight-five indicators were used to in studies measuring water regulation. Most common indicators included yield, water holding capacity/soil moisture retention, potassium, pH, particle size, water use efficiency, runoff, water infiltration rate, temperature, income and carbon dioxide. Perception of water quality was measured in six studies. Electric conductivity (liquids), cation exchange capability, dissolved organic carbon, and turbidity/water stable aggregates were measured in four studies. Metrics of evapotranspiration, groundwater depth, and erosion control were measured in three studies, and surface flow and base saturation in two studies

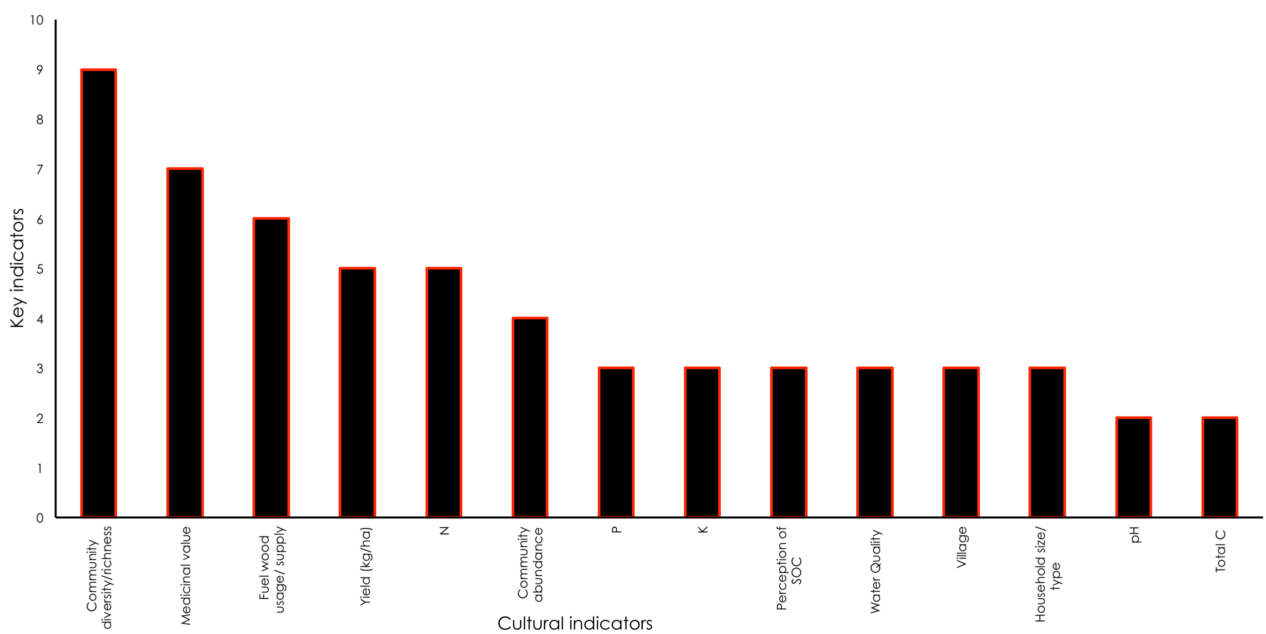


Fig. 14 Cultural service indicators. Forty-three indicators were used in studies measuring cultural services. Social indicators (e.g. spiritual and symbolic value) were the best represented cultural service ($n = 10$ articles), followed by educational ($n = 8$), aesthetic/bequest ($n = 8$) [67], recreational ($n = 6$), and tourism/ornamental value ($n = 5$). Methods applied included: a preference-based analysis procedure [67]; ethnography [64]; transect walks; semi-structured interviews [68]; stakeholder workshops [67]; focus groups; and life-history interviews [69]. In particular, religious value was commonly inferred by identifying sacred sites, locations where ritual practice was carried out, and the number of ritual artefacts used for festivals and weddings [67]. Other studies used the proxy of farmers' donations of cereal grains to religious institutions [67]

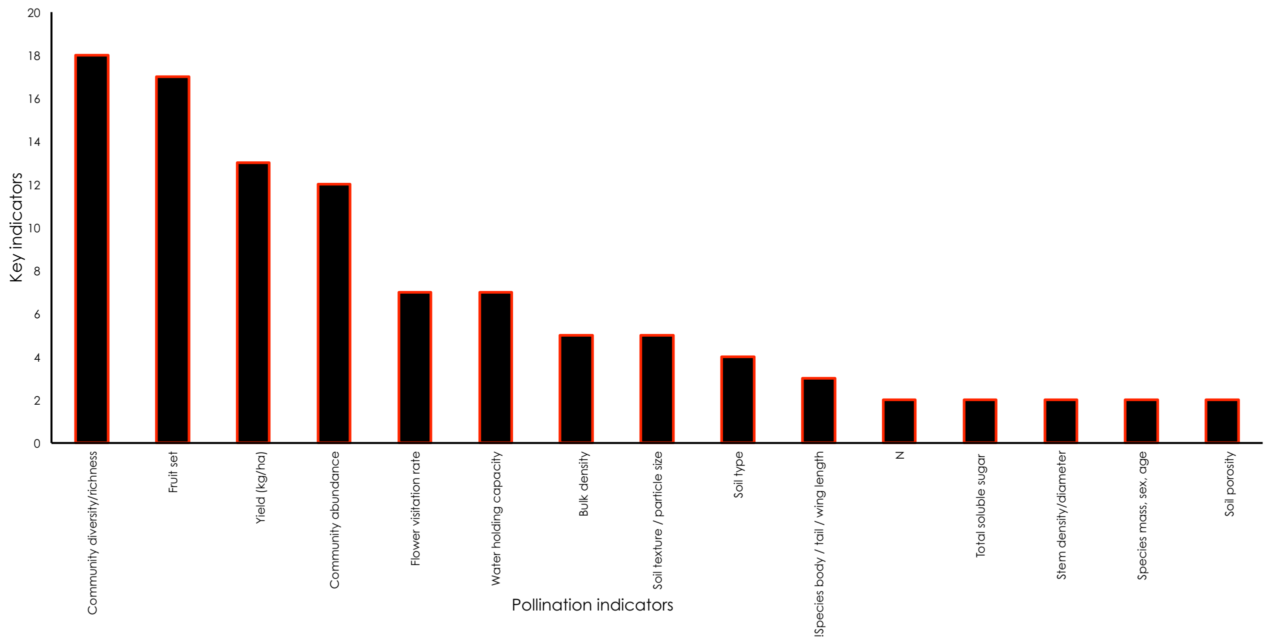


Fig. 15 Pollination service indicators. Thirty-five indicators were used in studies measuring pollination services. Most frequent measures of pollination were community richness/abundance (15 %, $n = 18$), fruit set (14 %, $n = 17$), yield (10 %, n = 13), community abundance (10 %, $n = 12$), and finally flower visitation (6 %, $n = 7$)

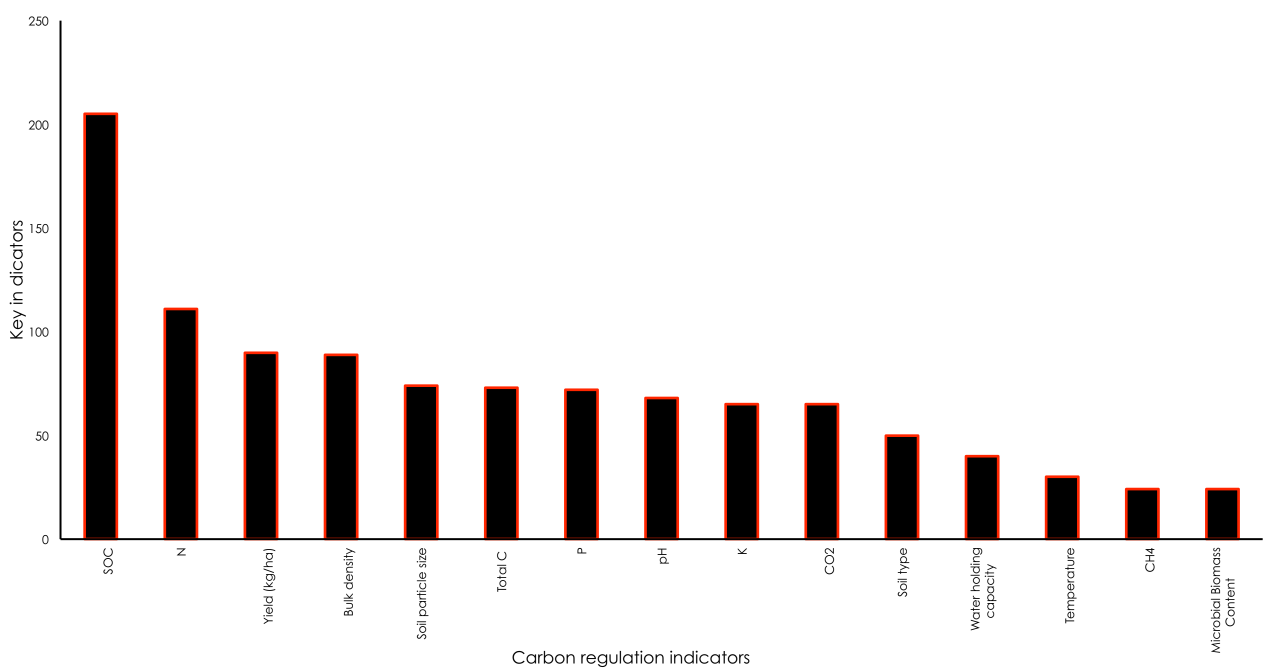


Fig. 16 Carbon regulation indicators. Eight-five indicators were used in studies measuring carbon regulation. Most common indicators to measure carbon pools in soil, soil litter or in biomass were SOC (14 %, $n = 205$), N, P, K, yield, bulk density, soil texture, total carbon, and pH. Sixty-five studies measured carbon dioxide (CO_2). Fewer studies used proxies of methane (CH_4) (2 %, $n = 24$), stem density/diameter (1 %, $n = 17$), crop height and survival rate of trees (ea. 0.3 %, $n = 4$)

Table 9 Overall outcomes on ecosystem service provision and yield, as reported by authors

Broad outcomes	ES improved	ES declined	ES mixed	ES same	Yield total
Yield improved	181	3	24	3	211
Yield declined	5	5	6	2	18
Yield mixed	27	2	39	1	69
Yield same	6	1	3	10	20
ES total	219	11	72	16	318

Table 9 shows the conclusions drawn by study authors, based on their results for yield and ecosystem services outcomes: 181 studies claimed on-farm conservation land management both improved ecosystem services and yield. This finding is a key topic for further exploration in a systematic review that includes statistical analysis (*ES* ecosystem service provision)

improvement in yield but decline in ecosystem service provision. Although useful for broad interpretation, in the first instance, further research into specific pathways of change in ecosystem service provision is necessary.

Discussion

General discussion

The systematic map illuminates some general trends in the available evidence measuring the effectiveness of on-farm conservation land management for preserving or enhancing ecosystem services.

Currently, the types of interventions reported are closely related to contemporary understanding and priorities in agriculture, and in particular conventional agricultural research. The review showed most indicators measured have a strong association with crop productivity, economic considerations being key drivers of farmers' decision-making. Of particular note, a higher number of studies assessed inorganic fertiliser in contrast with organic fertiliser.

While previous reviews suggest that most assessments measured pollination and provisioning services (e.g. [79]), half of the studies in this review measured supporting services (55 %) and one-third measured regulating services (33 %). The majority of these studies have measured the effects of production on carbon sequestration and storage (26 %), nutrient cycling (17 %) and soil regulation (19 %). This emphasis could be attributed to recent concerns about the effects of increasing atmospheric concentration of CO_2 and other GHGs on climate change, and growing interest in how terrestrial sinks can mitigate warming.

While the review covered a wide range of management practices, a large proportion of studies assessed tillage (24 %) and organic fertilisation regimes (24 %). Since 2011 [80, 81] there has been a notable increase in interest in three particular soil conservation practices, namely mulching (~4.5-fold), organic fertiliser (~threefold) and alternative tillage regimes (~twofold). This suggests a shift in the research agenda towards agro-ecological practices. However, the practices currently studied are still limited in scope, focusing on the effect of farmyard manure fertilisation (10 %), no tillage (9 %), multipurpose or multistorey cropping (8 %), or dry fallowing (5 %).

The systematic map found an exponential increase since 1992 in publications covering the topic of on-farm conservation land management. Based on analysis of date of publication of these articles, we suggest increases could be associated with (1) the publication of seminal reports (e.g. MA in 2005 [6]), TEEB in 2008 [12]); (2) the launch of the 'climate-smart agriculture' concept of the FAO in 2010 [80, 81]; (3) international meetings (e.g. the Rio Summit in 1992 and Rio + 20 in 2012); (4) the formation of international alliances (e.g. Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) in 2012); and/or (5) a general increase in financial investment, greater corporate sponsorship, and a wider variety of finance tools available for ecosystem service valuation [82].

We identified three geographical gaps in research of on-farm conservation land management. First, there is a dearth of research in Africa (constituting 25 % of studies) and in Central and Latin America (constituting 25 % of studies), dwarfed in comparison to the good representation of studies in Asia, particularly India and China. Second, few studies were conducted at the regional and landscape levels, which may skew results away from ecosystem processes that operate at these scales (e.g. certain hydrological services). Third, more studies were conducted on research stations (76 %) than on working farms; large-scale/commercial farms constituted only 7 % of studies and combined assessments of small- and large-scale farms constituted 2 %.

These trends may be associated with a broader movement away from experimental work towards theoretical work [83]. The trend could also be as a result of methodological barriers to working in the field (e.g. labour and time investments, site access, permissions, language, payments), and other practical reasons that require researchers to draw on existing networks and institutional affiliations, rather than setting up new field sites. The reported research is therefore biased towards a limited set of known research areas or stations. More work is needed to connect broader scale modelling and field-based, ground-truthed data. Centralising open access data can help to ensure the effective recording and use of this valuable information when it is collected.

We further identified that multiservice, mixed-method, and multidisciplinary studies were conspicuously absent, even though the importance of multidisciplinary research is widely acknowledged [84]. Most studies (92 %) measured just one or two ecosystem services. Only one study measured perceptions and management of carbon storage and sequestration even though this was one of the most frequently measured services. Further, only four studies used an experimental design to assess cultural services, while the remaining studies were non-experimental. Cultural services also constituted the smallest proportion of studies (3 %), confirming that we have limited data (not only in agricultural landscapes) of non-tangible benefits and non-marketable functions of ecosystem services [67, 85]. Interestingly, only five studies on tourism value in agriculture as were detected in our search, and six in recreation, aesthetic, or educational value. Therefore, our results indicate a clear need for a broader suite of indicators to be studied in new research projects so that land management decisions are based on a more realistic array of ecosystem outcomes.

The review further showed that most studies took place on a time-scale that is inadequate for understanding whether impacts of management decisions are temporary, or have more permanent consequences for ecosystem services (54 % were <4 years). This presents a particular challenge for ecosystem processes and services that operate on longer time-scales in the order of decades, such as soil carbon storage. Therefore, more long-term experiments and monitoring are needed.

Finally, the finding that most studies assessing the effectiveness of on-farm conservation land management are published in journal articles (97 %), only one-third of which are open access, suggests that access to this knowledge may be limited for decision-makers outside of academia. Few studies based on direct local evidence are available in the literature published by relevant organisations and institutions (2 %). This raises a potential disconnect between the types of management practices promoted by organisations likely to have a presence in the field and the empirical evidence of their efficacy in promoting ecosystem service delivery.

Limitations in searching

We acknowledge that studies published before 1984 are less likely to be available in electronic format and were therefore not a source of literature for the current systematic map. Although the search strategy was widely circulated amongst our stakeholder groups and published in the protocol [32], there may have been terms we may have missed to produce additional records, such as practices (e.g. direct and mulch tilling) or ecosystem services (e.g. soil organic carbon stores in cases where the phrase 'carbon sequestration' is not used in the title, abstract or keywords). Low representation of particular taxonomic groups or crops may be a result of the exclusion of biomes in the search. Two of the five journals selected during stakeholder workshops for targeted searches (Field Crops Research and Agriculture and Ecosystems and Environment) were the most frequently cited journal titles, which may have resulted in familiarity bias [86]. Websites from regional agricultural research consortiums, rather than national research agencies were selected to reduce bias towards governmental agencies, although might have limited the number of studies from some countries. Bias towards countries most frequently studied is also likely to be reflected in the language and country population densities (e.g. China, Brazil, India and Mexico).

Limitations in interpretation

Limitations in interpretation could have arisen from categorising overlapping practices, aggregating multiple practices, or reporting the number of articles rather than multiple outputs of one study. Further, as this map did not set out to evaluate the quality of evidence, results may illuminate evidence gaps, but we cannot infer the robustness of studies beyond whether they are experimental, quasi-experimental, or correlative. Although the terms experimental, quasi-experimental, or correlative were defined, there is also room for interpretation of what is randomised or manipulated—thereby introducing the possibility of an overrepresentation of experimental studies. Nevertheless, users of the map may read the studies relevant to the ecosystem service, intervention or crop of interest in order to assess their quality using existing criteria [23].

Conclusion

This systematic map provides a robust synthesis of the evidence on the effectiveness of on-farm conservation land management for preserving and enhancing ecosystem service provision in agricultural landscapes in developing countries. The systematic map of 746 studies, in combination with an interactive online platform that geographically maps results (accessible at https://oxlel.zoo.ox.ac.uk/resources/ecosystem-services-onfarm-conservation-map), allows users to interrogate different aspects of previously fragmented evidence through a defined database field structure. The database provides evidence concerning a wide range of conservation land management practices—particularly tillage, agroforestry, organic fertilisation and water conservation—which impact key ecosystem services—particularly carbon sequestration, soil/water regulation, nutrient cycling and biodiversity.

Implications for policy and management

Natural landscapes will continue to be converted to agricultural landscapes, and extensive land converted into intensive land, with 7.5 million km^2 expected to be converted by 2050 [87]. In the face of unprecedented agricultural expansion and land use change, in the future there is a high likelihood the management will be geared to favour some services (e.g. provisioning) over others (e.g. supporting). While future work is needed on alternative public and private payment schemes, institutional arrangements, and the important matter of explicit trade-offs arising from conservation management, results emphasise that more value should be attached by development planners to the importance of minimal input, multifunctional agriculture, sustainable intensification, and conservation agriculture.

Implications for future agriculture and ecosystem services research

Future research needs include:

- long-term experiments (20 years+) that assess temporal stability, and response and recovery from a variety of disturbances, particularly of biodiversity on farms and functional diversity;
- studies in 28 countries, namely Afghanistan; Algeria; Bhutan; Botswana; Burundi; Cambodia; Central African Republic; Chad; Comoros; Congo; Democratic Republic of Congo; Djibouti; Eritrea; Guinea-Bissau; Kyrgyzstan; Lesotho; Liberia; Mauritania; Mongolia; Namibia; Samoa; São Tomé and Principe; South Sudan; Sierra Leone; Solomon Islands; Somalia; Tajikistan; and Yemen.
- studies in the regions of Central Africa; North Africa; Central Asia; and Oceania;
- cross continental and cross-country studies;
- research on working farms, rather than on research stations. Empirical studies in smallholder farming systems are needed;
- research on provisioning services in agricultural landscapes, namely building material, pollination, fuel wood, non-timber forest products, and medicinal and aromatic plants;
- studies in vegetable cropping systems. Future research may also review the world of research institutions such as the World Vegetable Centre (AVRDC);
- studies measuring cultural services and non-tangible benefits;
- studies measuring ecological variables in conjunction with farmers' perception;
- studies assessing multiple ecosystem services and their interactions; and
- studies of perennial crops, especially cash crops, such as tobacco and rubber.

Implications for extension of the systematic map

The systematic map is easily updatable and may be extended to include additional data analysis. An extension of the map might consider key economic and livelihood metrics, funders of studies (to test whether funding may determine emphases on fertilisation and major commodity crops, for example), and other likely environmental variables that could lead to heterogeneity in determining overall effect of land management (e.g. soil type, mineral texture class, altitude, slope, species mix in cropping systems, previous land uses, and surrounding land uses) [32]. The systematic map could also be expanded to include studies in other major languages, especially French and Spanish.

Implications for future systematic reviews

Future work could usefully look in more detail at elements of this systematic map through a full systematic review. Such systematic reviews could focus on individual crops, or particular regions, indicators, or management strategies. We identified the following key questions that appear to have sufficient primary research to carry out systematic reviews, and have current global relevance to policy and management:

- 'What is the ecological impact of key agroforestry crops with therapeutic properties and livestock fodder crops (including *Adansonia digitata* (baobab) [88], *Moringa oleifera L.* (moringa) [89] and *Vitellaria paradoxa* (shea tree) [90]), on improving smallholder farmer livelihood in Sub-Saharan Africa and Asia?'
- 'What are the economic, ecological and social costs and benefits for smallholders of shifting from conventional to short maturing seed varieties?'
- 'What is the impact of livestock, population density and land holding size on organic manure availability and soil organic carbon?'
- 'What is the impact of intercropping leguminous cover crops and traditional staple cereals (e.g. sorghum, maize and cassava) on soil/water regulation, and nutrient cycling?'
- 'What is the impact of fire management regimes on carbon sequestration, water resources, air quality, and biodiversity in developing regions?' (While previous reviews have been conducted in specific countries, such as the US [91], Australia [92], and Ghana [93], we identified no such regional reviews.)

- 'What is the impact of large-scale or commercial production on preserving ecosystem services in palm oil, jatropha, and soya bean cropping systems?'

Additional files

Additional file 1. Definitions and countries included in the systematic map.

Additional file 2. Records generated for specific searches.

Additional file 3. Meta-analyses and systematic reviews.

Additional file 4. Studies excluded at full text with reasons for exclusion.

Additional file 5. Coding tool for systematic map.

Additional file 6. Systematic map database on on-farm conservation land management and ecosystem services.

Additional file 7. Studies included in the systematic map database.

Additional file 8. Agroforestry tree crops studied in articles included in the review, with scientific name with common name and uses.

Additional file 9. Tabulation of conservation land management and interventions and ecosystem service measured.

Abbreviations
AGRICOLA: National Agricultural Library and Citation Database; AGRIS: Agricultural Science and Technology Information Systems; AVRDC: World Vegetable Centre; C: carbon; CABI: CAB International, formally Commonwealth Agricultural Bureaux; CEE: Collaboration for Environmental Evidence; CH_4: methane; CIFOR: Centre for International Forestry Research; CIMMYT: International Maize and Wheat Improvement Centre; CAADP: Comprehensive Africa Agriculture Development Programme; CO_2: carbon dioxide; DFID: UK Department for International Foreign Development; ES: Ecosystem Service; ESPA: Ecosystem Services and Poverty Alleviation; FAO: United Nations Food and Agricultural Organisation; GHG: greenhouse gases; ICRISAT: International Crops Research Institute for the Semi-Arid Tropics; IPBES: Intergovernmental Panel on Biodiversity and Ecosystem Services; IRRI: International Rice Research Institute; IWMI: International Water Management Institute; K: potassium; LIFDC: low-income food deficit countries; MA: millennium ecosystem assessment; Mg: magnesium; N: nitrogen; N_20: nitrous oxide; NO_3: nitrate; NTFP: non-timber forest products; ODI: Overseas Development Institute; P: phosphorus; PDF: portable document format; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-analyses; SOC: soil organic carbon; TEEB: The Economics of Ecosystems and Biodiversity; US: United States; USDA ARS: United States Department of Agriculture's Agricultural Research Service; UK: United Kingdom; UK NEA: United Kingdom National Ecosystem Assessment; WB: World Bank; WOS: Web of Science; WRI: World Resources Institute.

Authors' contributions
JT jointly with GP conceived the study and secured funding support. JT, GP, and RF co-wrote the manuscript. JT coordinated the data extraction. JT, RF and GP implemented the search, screening and data extraction. JT and DB conducted the mapping. JT and RF conducted analysis. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

Availability of data and materials
The datasets supporting the conclusions of this article are included within the article and its additional files.

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